MAY 1960

NUCLEONICS

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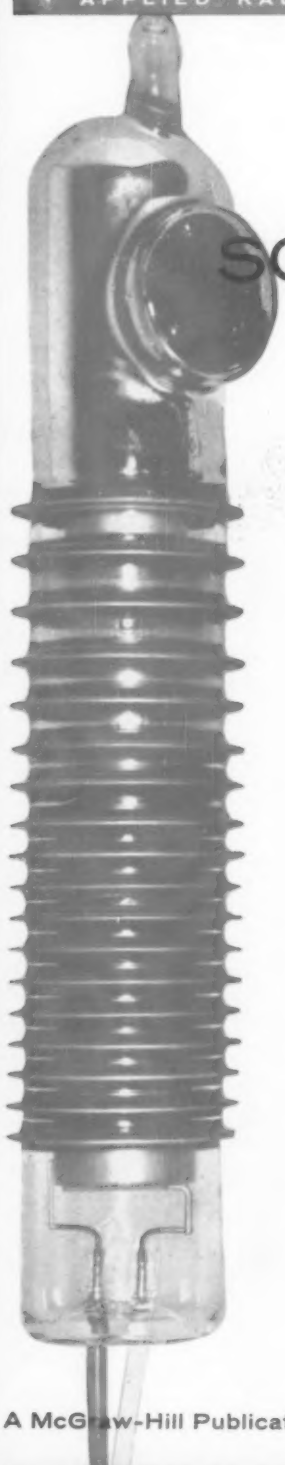

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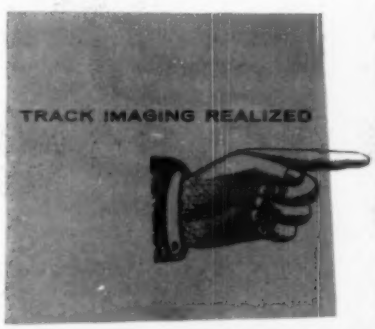

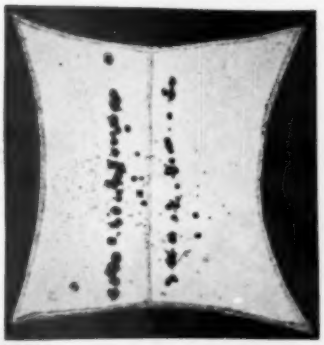

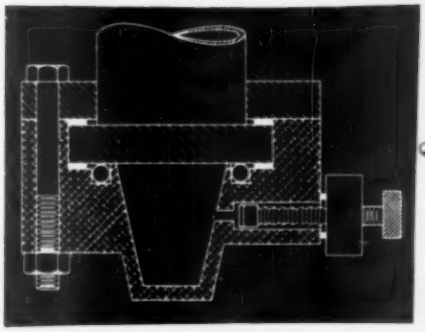

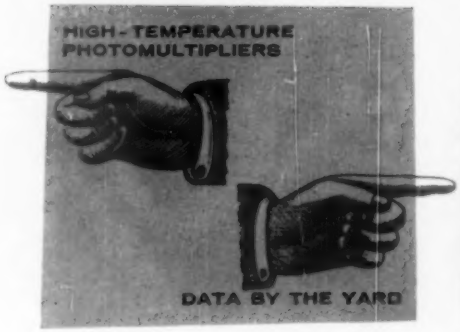

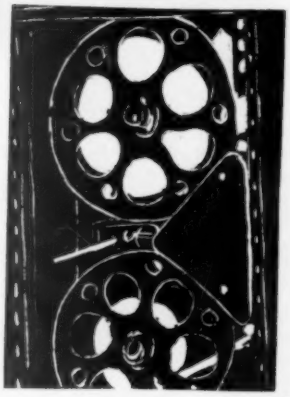

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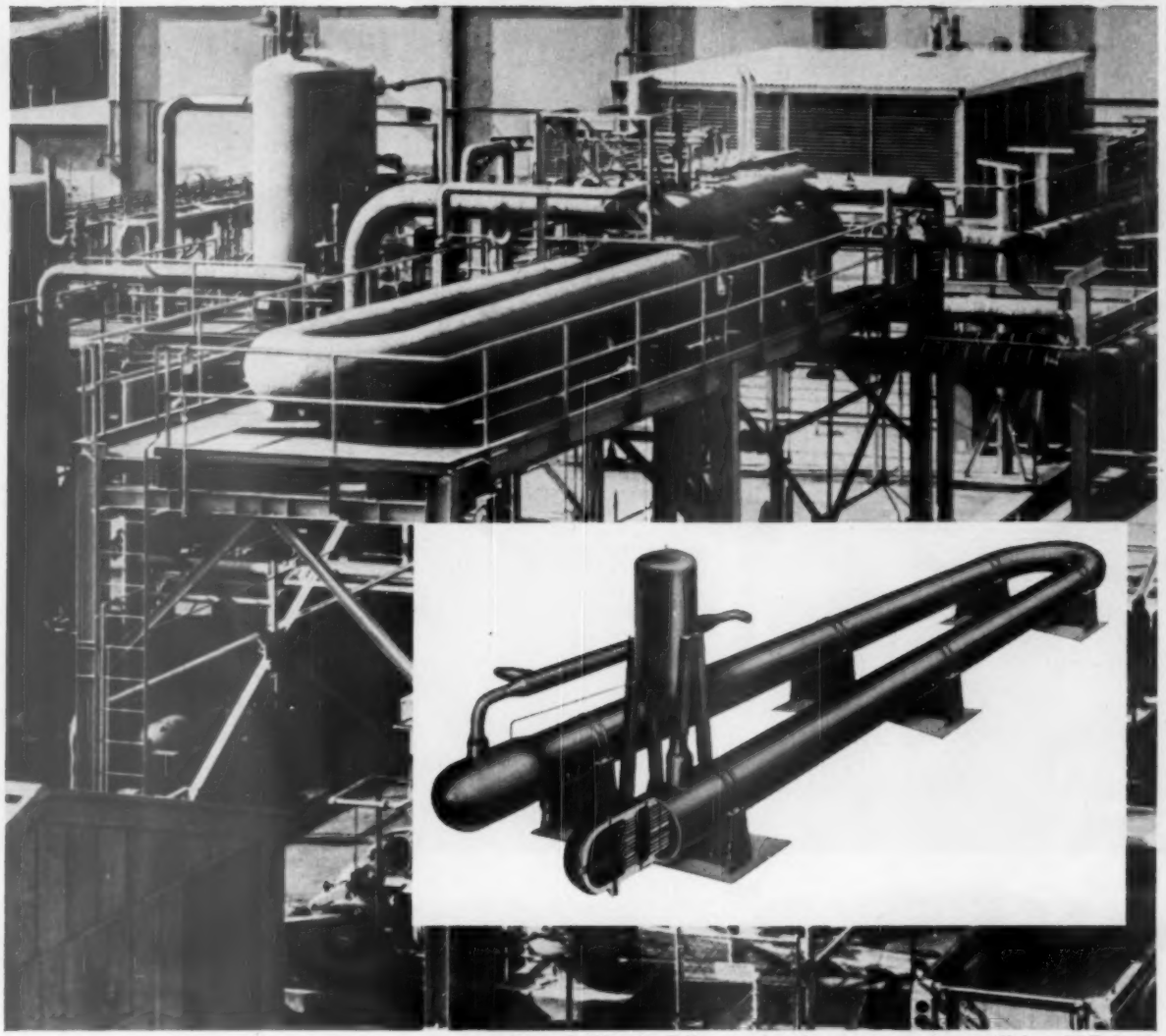

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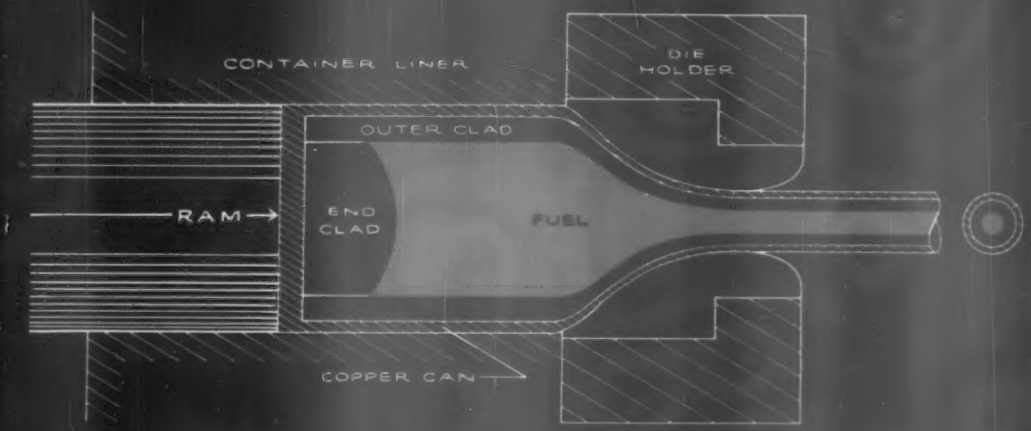

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...about NUCLEONICS

Crystal Counters Return

One of the surprising things about this year's Scintillation Counter Symposium (see p. 85) is that the highlight of the meeting was the session devoted to a counter that doesn't scintillate at all—the semiconductor detector. This was completely appropriate, however, since semiconductor detectors are an important new field for those interested in nuclear instrumentation and the Scintillation Counter Symposium is one of the principal forums for those interested in nuclear instrumentation.

Actually, crystal counters were an important part of the very first "Conference on Scintillation Counters and Crystal Counters" held at the University of Rochester in July, 1948. Scintillation counters rapidly outstripped crystal counters so that when the second such conference was held less than a year later it was called simply the "Scintillation Counter Symposium" and only one paper was concerned with crystal counters.

After an absence of nearly 11 years the crystal counter has re-entered the symposium. Its re-entry is spectacular and vigorous, and it's in new garb—not the conductivity counter of old but as a tiny *p-n* junction diode that affords remarkably good resolution for heavy particles.

A Problem of Communication

It's interesting to consider why 11 years had to elapse between the first strivings for a successful nonscintillating solid-state detector and the present emergence of the semiconductor junction detector with all its promise. Partly our gradually vanishing ignorance of the solid state is to blame, but some of the cause is in a failure of communication between solid-state and nuclear people.

As for the physics: early crystal counters were of the "single-conductivity" type. Two electrodes provided ohmic contact to opposite faces of a block of high-resistivity material such as diamond. Unfortunately, such detectors gradually polarize under bombardment and ultimately fail. (Silicon, which is used in the new junction detectors, can not be used in the single-conductivity type because its resistivity is too low, at least at room temperature.) Only with McKay's recognition that the high fields and low leakage current of a reverse biased *p-n* junction could provide the appropriate conditions was the ground laid for today's semiconductor detectors. But even McKay's work goes back to 1949. True, semiconductor materials and fabrication techniques for them had to be improved as part of the general advance in transistor science, but something else contributed to the delayed advent of the new devices.

We feel that a real contributing factor was the failure of nuclear people to stay abreast of what the solid-state folks were doing. Conversely, we feel that if solid-state researchers were aware of nuclear requirements they could more readily have appreciated the potential in diodes. We think it is not without significance that the laboratories that have been at the forefront in supporting the new detector breakthrough have both solid-state and nuclear competence. Conversely, it is encouraging to see at least one of the major solid-state laboratories enriching its research program with nuclear interests. But even now one wonders if there's communication enough.

—The Editors

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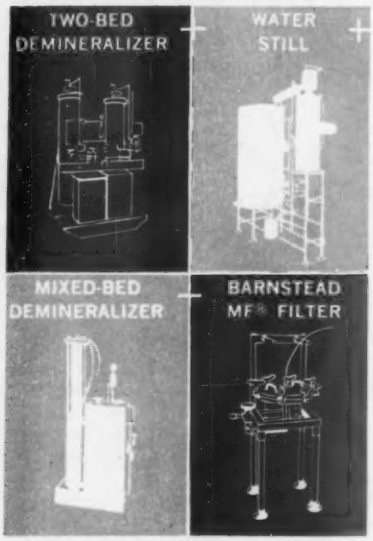

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NUCLEAR REACTIONS

Plant Capacity Factor

DEAR SIR:

In the preparation of estimates and comparisons of nuclear energy costs, the degree of utilization of the nuclear power plants involved is of great importance. This is given by the so-called plant factor, or better by the plant capacity factor, which, according to the American Standards Association, ". . . is the ratio of the average load on the plant for the period of time considered, to the aggregate rating of all the generating equipment installed in the plant."

Thus, in simple words, the plant factor provides an idea about the operation of the plant, on which, especially in the case of high-investment plants as the nuclear power stations, the kilowatt-hour cost is very strongly dependent. Its significance, therefore, in estimating energy costs and in providing an equal basis for power cost comparisons between various nuclear power stations is obvious.

I do not know why, but almost every one engaged in nuclear power uses, instead of the above, the term "load factor," which, according to ASA, ". . . is the ratio of the average load over a designated period of time to the peak load occurring in that period."

The load factor, therefore, although a very useful quantity in describing the form of the actual load supplied by the generators, gives no idea, whatsoever, about the degree of utilization or the output of a generating plant. A load factor of, say, 100% can correspond to any plant factor from practically zero to 100%.

Of course, it is well known by now that when a nuclear spokesman says "load factor" he means "plant factor," so there is no great danger of confusion. But once defined and agreed upon, terms should be used properly afterward.

—A. ALEXIOU
Public Power Corp.
Athens, Greece

EDITOR'S NOTE: Mr. Alexiou is correct. NUCLEONICS, which has been guilty of the error, will correct its ways. As nuclear engineers interact more with utility engineers they owe it to them to use utility terminology correctly. This is but one facet of the larger problem of getting to know better the needs of the group that will someday be the largest consumer of nuclear power.

Modern Flux-Trap Reactor

DEAR SIR:

Early in 1956, work that was carried out at New York University showed that it was possible to obtain a high thermal flux at a low power by using a fast or intermediate reactor with a central moderator zone.

The original calculations were made by Dr. Milan Osredkar, who is now in the Reactor Division of the International Atomic Energy Agency. He investigated the following systems: (1) Thermal reactors with light water or heavy water for the inside region. (2) An intermediate reactor having ten times the fuel-to-moderator ratio of the MTR and a central zone of light water. (3) Fast reactors with a thermal-neutron absorber at the interface and central regions of light or heavy water. (4) A fast reactor without absorber at the interface and with a central zone of light water. (5) A fast reactor with absorber at the interface and with a double inside region of light and heavy water (this was suggested by Prof. Wigner).

In spite of the relatively active work of the past four years, it is doubtful that the best design of a flux-trap reactor has been determined. Relatively little work has been done on fast systems. Further work should be done on flux converters—namely, methods of changing from thermal to fast flux or vice versa.

It is possible that a mixture of light and heavy water might be better than either one alone for the central region or outer reflector. The effect of poisoning the fuel region should be studied, since this should increase the ratio of fast to thermal flux.

It is possible that a material having a greater hydrogen concentration than light water would give better flux peaking. The use of materials such as liquid ammonia or methane in the central zone might also favor flux peaking, since the cross section of hydrogen increases sharply at low energies. The scattering cross section of ortho-hydrogen is 128 barns at very low temperatures because of the effect of nuclear spins. It is possible there may be other molecules having very high cross

sections at low temperatures; if so, these would be of interest to designers of flux-trap reactors.

It is possible that a flux-trap reactor could be operated under transient conditions to give an extremely high flux for a short period of time.

By using a little imagination, I believe it is possible to build within the next few years a reactor having a steady-state thermal flux in excess of 10^{16} at a power of about 100 megawatts.

—Richard Stephenson
University of Connecticut
Storrs, Connecticut

Dear Sir:

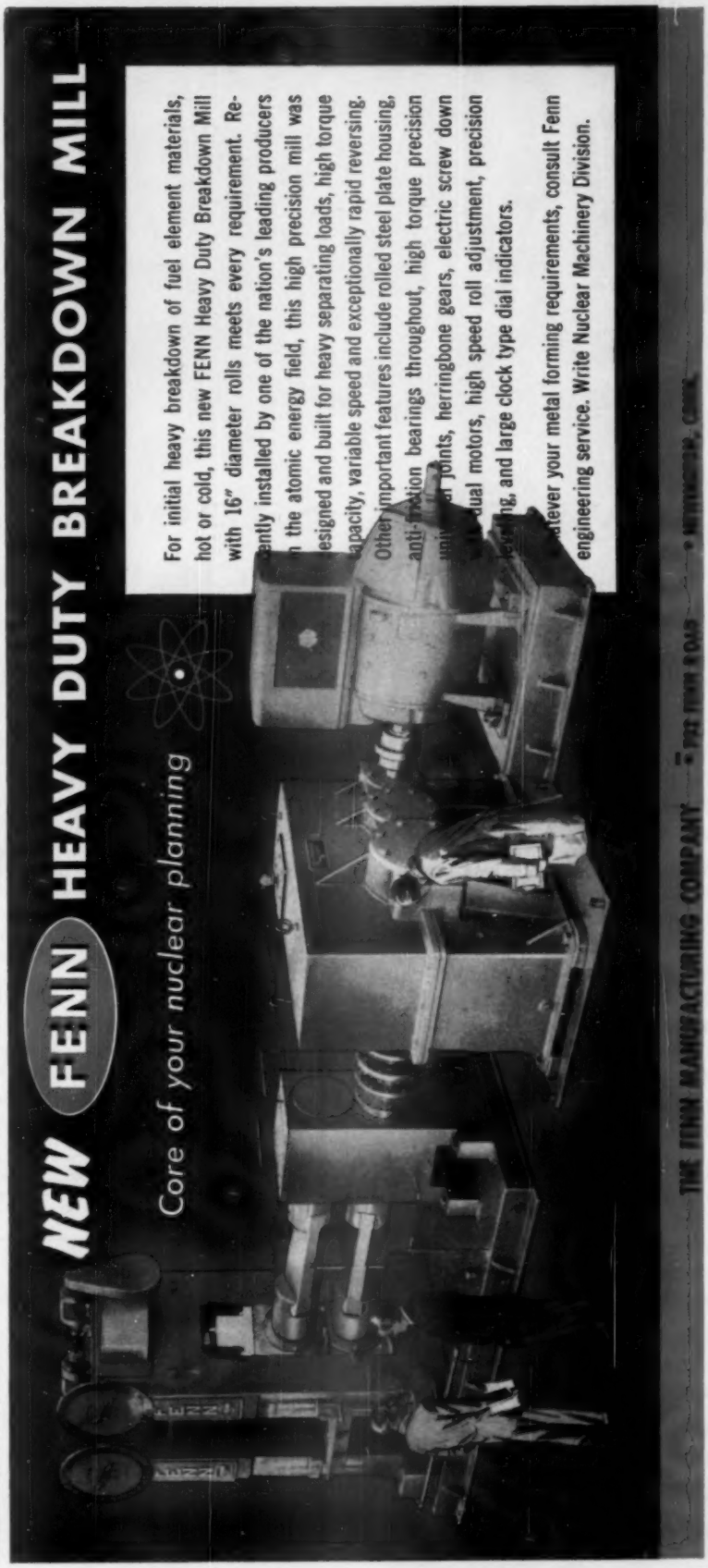
Thank you for the copy of Prof. Stephenson's letter. The comments of our technical people are as follows:

1. The Russians have pursued the idea of intermediate flux-trap reactors. The results of an extensive critical experiment program on intermediate light-water-cooled and -moderated reactors were reported by Feinberg *et al.* at the Second Geneva Conference. The initial Russian work may predate the work of Osredkar.

2. The best design of a flux-trap reactor is closely related to the specific use for which the reactor is intended. If the best design refers only to the maximum point value of thermal flux which can be obtained, some of Stephenson's points are well taken. Within the framework of technical feasibility, economic prudence and purpose, a significant improvement of some of the design concepts proposed for isotope-production reactors, university training reactors and engineering testing reactors may be difficult.

The ratio of the fast to thermal flux in the fuel region does increase with an increased poison content because of the increased fuel inventory required for criticality and the spectral effects in increasing the fraction of epithermal fissions. The implication that the effectiveness of the flux trap depends significantly on this ratio is incorrect, however. The effectiveness of the flux-trap design is principally dependent on the fast-flux level or power density in the core. For a given reactor design and power level, this parameter is not significantly affected by the poison addition.

—Lawrence C. Widdoes, President
Internuclear Company
Clayton, Missouri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The 415 also provides zero suppression up to 100 full scales, permitting full scale display of one per cent variations of a signal. Once suppressed to zero, such variations may be observed on any of the next four more sensitive ranges without resetting the suppression.

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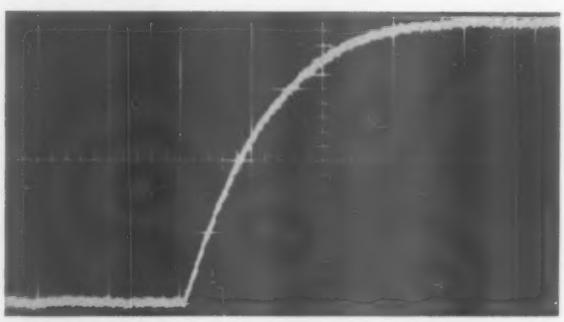

AN OSCILLOGRAM demonstrating response to a current step of 10^{-12} ampere. Input capacity is 35 picofarads ($\mu\mu$f). One major horizontal division equals 200 milliseconds.

BRIEF SPECIFICATIONS

RANGES: 10^{-12}, 3×10^{-12}, 10^{-11}, 3×10^{-11}, etc. to 10^{-3} ampere f.s.

ACCURACY: ±2% f.s. 10^{-3} thru 10^{-8} ampere ranges; ±3% f.s. 3×10^{-9} thru 10^{-12} ampere ranges.

ZERO DRIFT: Less than 2% of f.s. per day after warmup.

INPUT: Grid current less than 5×10^{-14} ampere.

OUTPUT: 1 v f.s. at up to 5 ma. Noise less than 20 mv.

RISE TIME: Typical values given in sec. to 90% of final values.

Range amps f.s.	C_{in} = 50 $\mu\mu$f seconds	C_{in} = 150 $\mu\mu$f seconds	C_{in} = 1500 $\mu\mu$f seconds
10^{-12}	.600	.800	2.5
3×10^{-12}	.200	.300	1.0
10^{-11}	.060	.080	.250
3×10^{-11}	.020	.030	.100
10^{-10}	.006	.010	.030
3×10^{-10}	.002	.003	.010
10^{-9}	.001	.001	.003
3×10^{-9} and above	.001	.001	.001

PRICE: Model 415, $750.00

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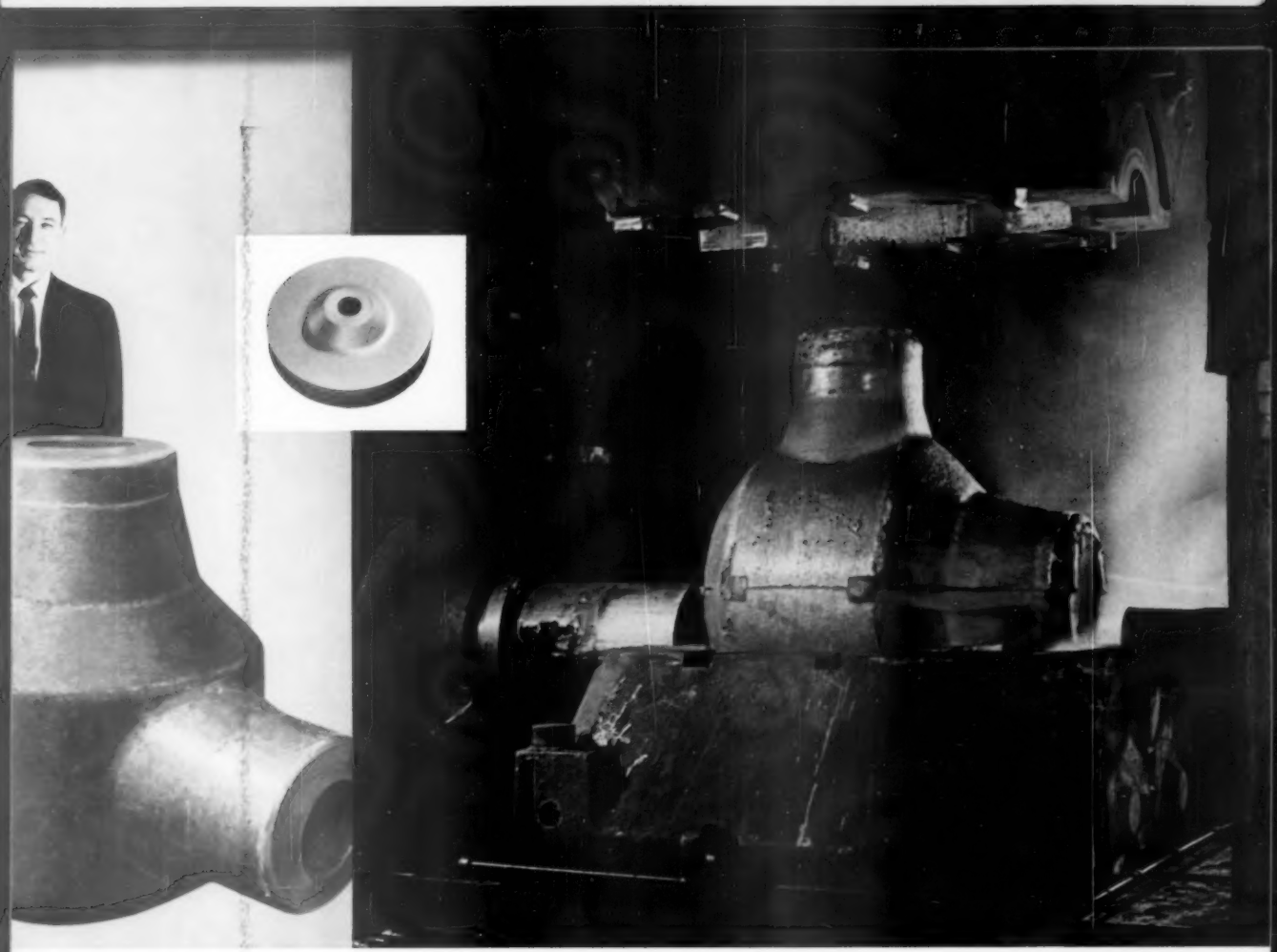

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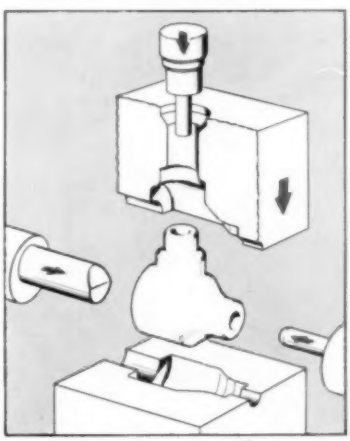

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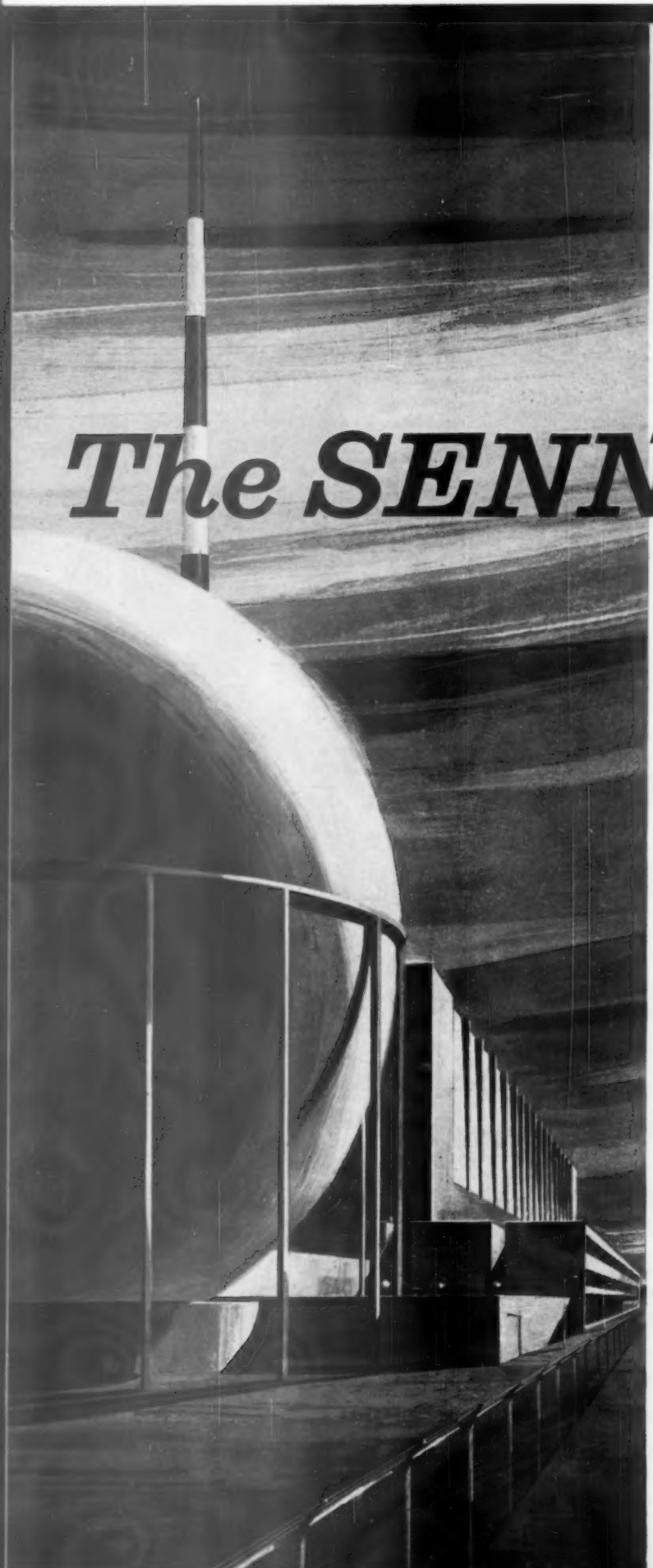


Progress toward lower generation costs
via the Boiling Water Reactor

The SENN Story

Garigliano Nuclear Power Plant design more than 30% complete—construction under way

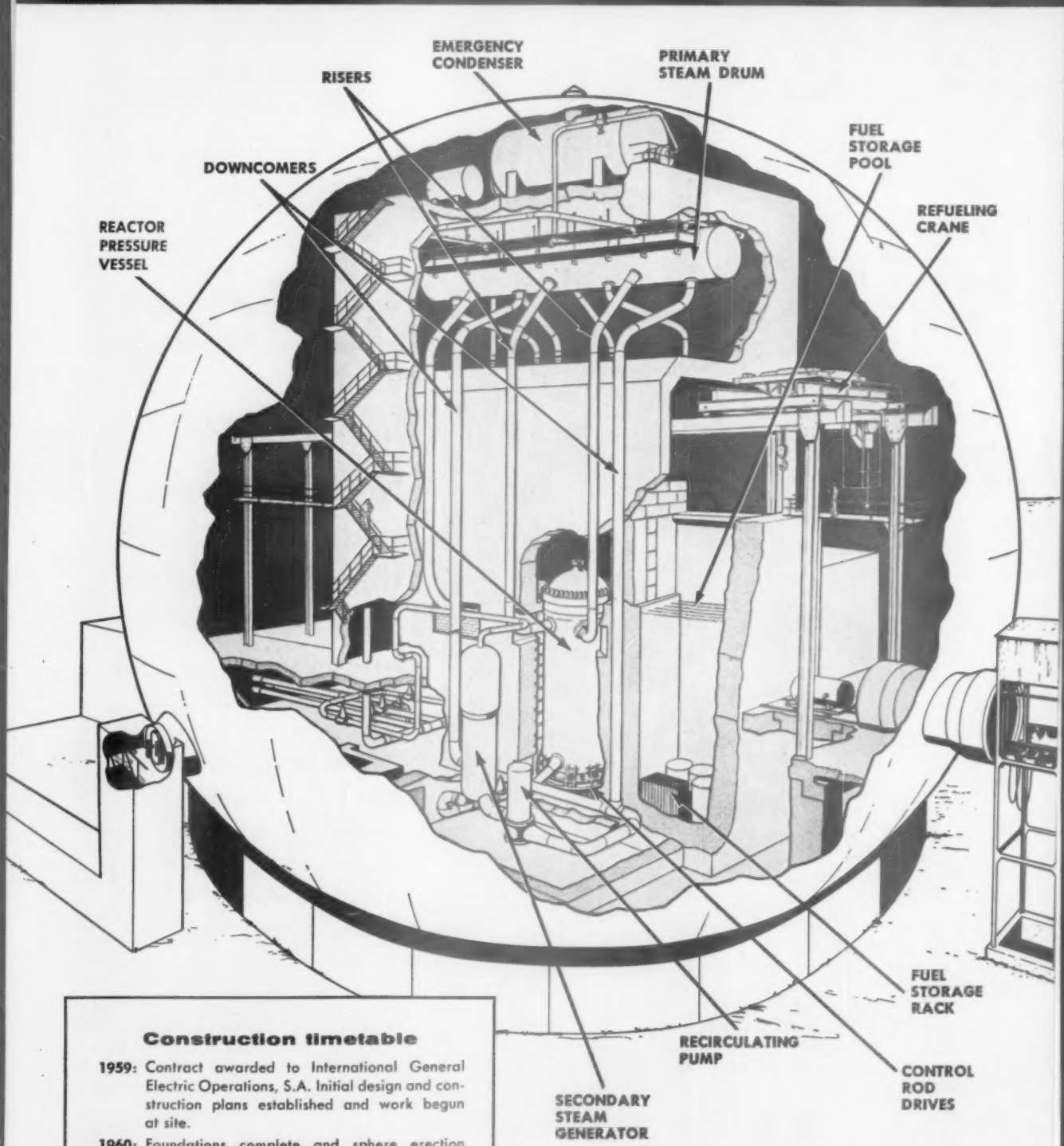
General Electric Boiling Water Reactor—of established design—selected over 8 other systems for Italy's Garigliano Plant because of high operating flexibility, good potential for improvement, lowest cost power production.

Progress Is Our Most Important Product

GENERAL ELECTRIC

U. S. A.

The SENN Story: established design keeps



Construction timetable

1959: Contract awarded to International General Electric Operations, S.A. Initial design and construction plans established and work begun at site.

1960: Foundations complete and sphere erection started. Nuclear system design complete.

1961: Sphere erection complete. Reactor pressure vessel fabrication complete.

1962: Pressure vessel installation complete. Nuclear steam supply equipment installed.

1963: First core loading. Plant operational.

SENN construction on schedule

Construction of Europe's first large boiling water nuclear power station, the SENN (Societa Elettronucleare Nazionale) 150,000-kwe Garigliano Plant, is already on schedule because of the established design of General Electric's Boiling Water Reactor. This reactor was selected over eight others because it will produce lower cost power, has high flexibility and good potential for future improvements.

Site preparation for this plant is well under way on the south bank of the Garigliano River, near Naples, and piling for the reactor structure is complete—fully a month ahead of schedule. Piling for the turbine building is proceeding on schedule for completion by July 1.

Flexibility in operation makes the boiling water reactor the outstanding type for power generation, both in normal operation and in response to network load demands. Designed to respond instantly to load changes, reactor power follows turbine load demands without necessity of control rod movement for load changes from 2/3 power to rated load.

Potential for future improvements, as a result of further strides in nuclear technology, is built into the boiling water reactor design. New, improved fuels can be utilized. The entire core may be readily removed and replaced. Further advances in reactor technology may permit increased specific power thereby reducing unit cost of total power produced.

SENN is another step in General Electric's continuing program toward economical nuclear power with the boiling water reactor. It is based on the established design technology of the Vallecitos Boiling Water Reactor and the Dresden Nuclear Power Station. Because of this foundation, SENN will be a proven system consisting of proven components when it goes "on-the-line" in 1963.

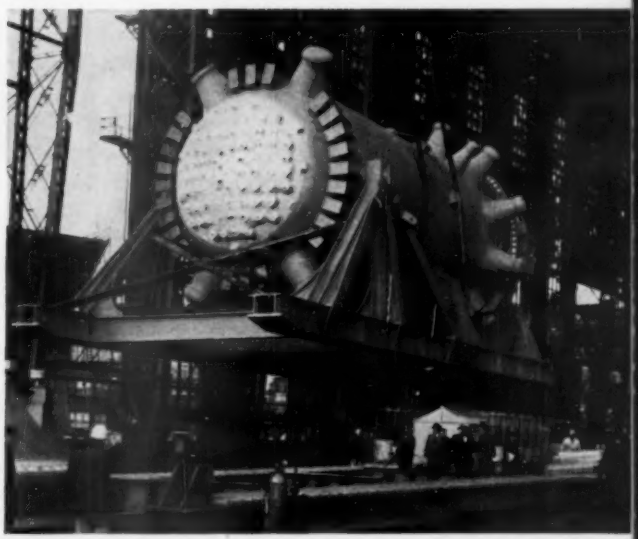
For further information, contact your nearby General Electric Apparatus Sales Office or write to General Electric Company, Schenectady 5, N. Y. Outside the United States and Canada, write to International General Electric Company, 150 East 42nd Street, New York 17, N. Y.

132-02

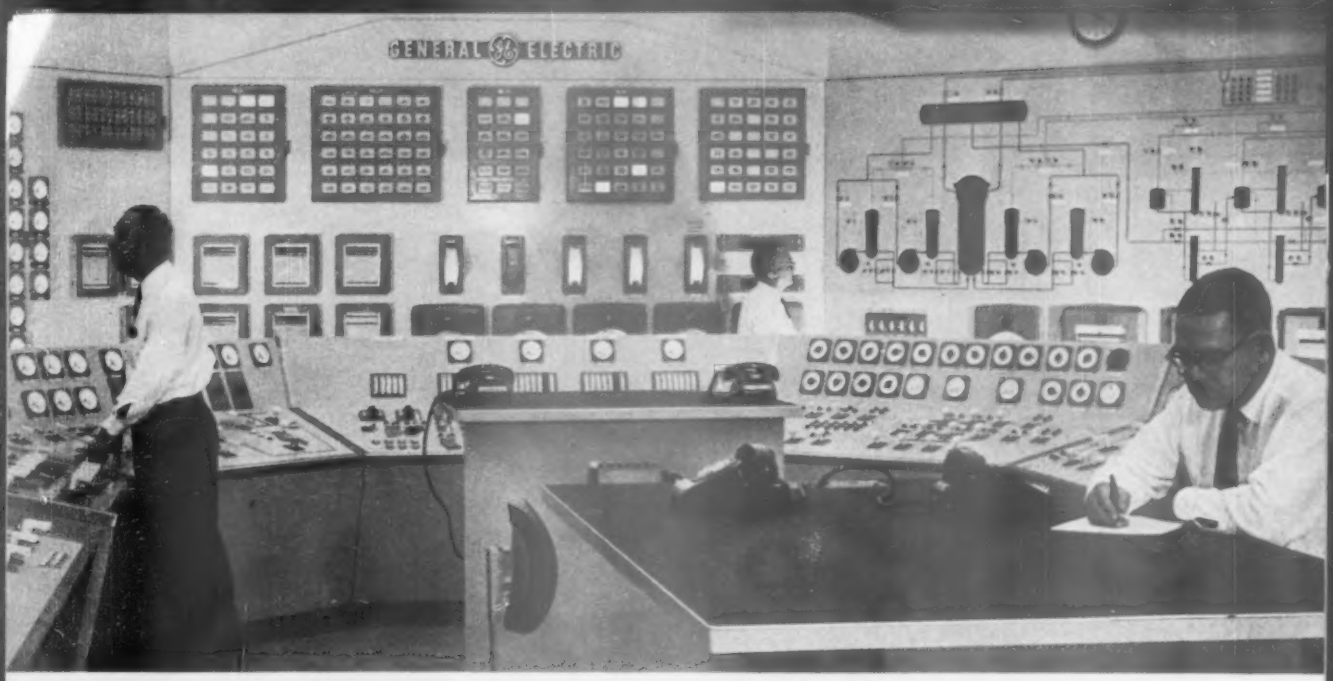
GENERAL ELECTRIC

U. S. A.

PILE-DRIVING OPERATIONS and the pile test program are under way at the site of the reactor containment sphere at SENN.



HUGE PRESSURE VESSEL for the Garigliano Plant, similar to the Dresden pressure vessel (above), is now being manufactured.



COMPLETE INSTRUMENTATION SYSTEMS, such as this one at the Dresden Nuclear Power Station, and individual instruments for wide application are engineered, built, and tested by General Electric at the Atomic Power Equipment Department in San Jose, California.

General Electric nuclear instrumentation . . .

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TESTS FOR ACCURACY and speed of response beyond specifications are standard at General Electric. Durability and maintenance-free operation are "built-in."

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3. Radiation monitoring equipment
4. In-core instrumentation

COMPONENTS:

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Catching Up with a Slippery Equation

What goes on when two moving surfaces are separated by a film of oil?

Simple question? Maybe, but engineers and mathematicians have been trying to answer this classic question of lubrication ever since Osborne Reynolds neatly stated the problem in equation form back in 1886.

Unfortunately, analytical methods for solving Professor Reynolds' partial differential equation worked only for unrealistic oil bearings, bearings with widths approaching zero or infinity. And approximate methods were crude, requiring a complete recalculation for each slight change in the bearing.

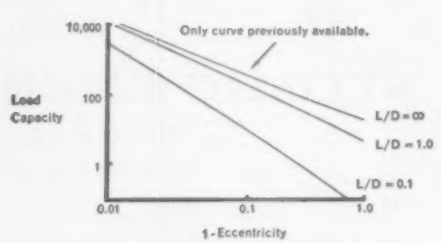
Recently, mathematicians at the General Motors Research Laboratories came up with the most versatile and efficient method of solution yet made. Their analytical method for solving the two-dimensional Reynolds' equation applies to all finite journal bearings — as well as other hydrodynamic bearings — with *no* assumptions or approximations about boundary locations. The new method uses a long-neglected energy theorem recorded by Sir Horace Lamb instead of the force relationship tried by Reynolds and others.

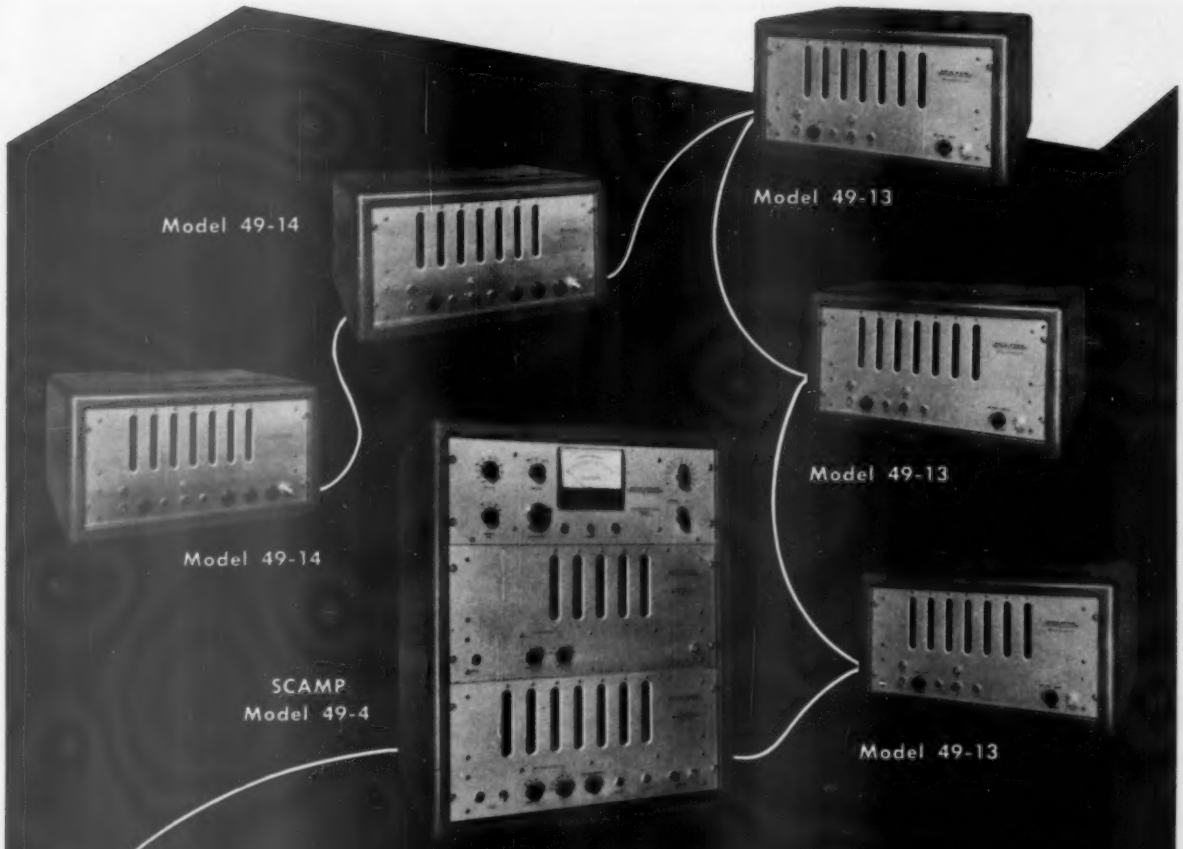
Besides being a valuable contribution to the theory of lubrication, this work has its practical side: namely, accurate, serviceable design curves for engineers. At GM Research, we believe delving into both the theoretical and applied sides of a problem is important to progress. It is a way of research that helps General Motors fulfill its pledge of "more and better things for more people."

General Motors Research Laboratories

Warren, Michigan

Hydrodynamic analyses have led to specific answers about bearing operation. Shown here are the oil pressure distribution (main illustration) and load-carrying capacity for a non-rotating journal with a reciprocating load.





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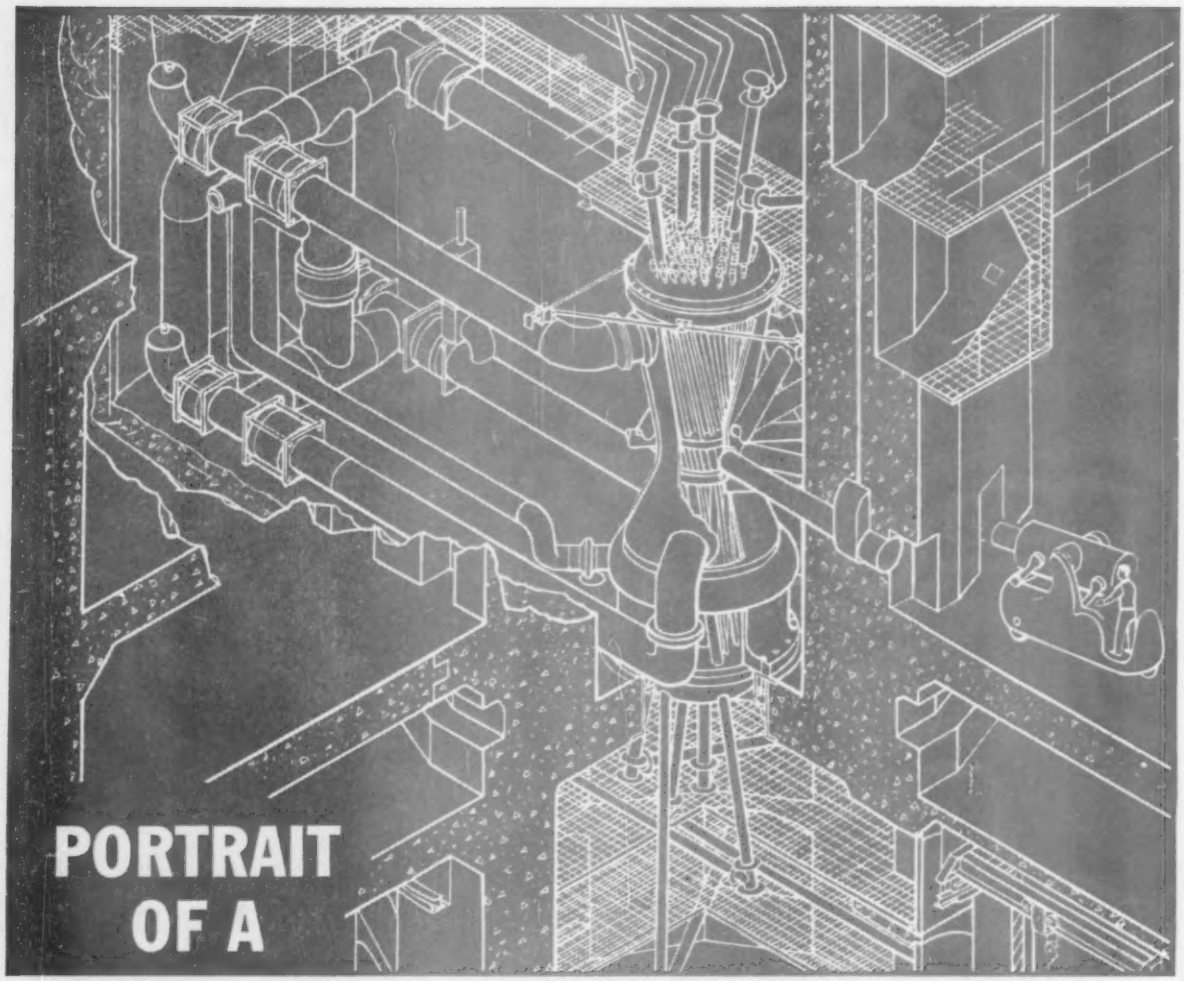

TEST REACTOR

Five nuclear reactors are in various stages of development at NDA. Each differs from the others, but all bear the stamp of true progress.

Progress in design is an NDA hallmark and accounts in part for its success in a demanding field. Equally important, however, is the ability of an organization to move from concept through engineering design, materials development, laboratory experimentation and critical testing. In these, too, NDA's reactors show invention and originality.

NDA's complete reactor capabilities are exemplified in METR (above), a 50-megawatt Materials and Engineering Test Reactor, the first of which is now under construction at Mol, Belgium. Beginning with the core itself, a unique design which combines extremely high neutron flux with simple, independent access to each fuel and experiment tube, METR I will be a vital part of one of the world's great nuclear centers. METR is typical of the family of reactors now under design or development at NDA for power, propulsion and research.

OPPORTUNITIES EXIST AT NDA FOR QUALIFIED SCIENTISTS AND ENGINEERS

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NUCLEONICS NEWS OF THE MONTH

JCAE Blocks Stanford Linac, Okays 3 Antarctic Reactors

In a highly unusual—if not unprecedented—action, the Joint Committee on Atomic Energy last month cut down the size of AEC's construction program for the coming fiscal year. AEC's authorization bill for fiscal '61 beginning July, was chopped from $293,876,000 to $211,476,000, as JCAE refused to authorize a '61 go-ahead on the $107-million Stanford linear accelerator but insisted on several other projects AEC had not formally sought.

The 15-Bev Stanford electron machine was not killed outright, rather postponed until next year by the Democratic leadership of JCAE. Sen. Clinton P. Anderson (D-N.M.), chairman, and other JCAE Democrats had been hinting loudly for some time that they were less than enthusiastic about the project and there was even some opposition at AEC (NU, March '60, 28).

Moreover, the huge machine has become something of a political football: some in Congress see it as possible trading material for the authorization next year of 636 Mwe in generating equipment at Hanford's New Production Reactor. Under the circumstances, JCAE approved only a $3-million design and engineering study on the project and will reconsider the machine itself next year.

Three Antarctic Reactors

With Sen. Henry M. Jackson (D-Wash.) taking the lead, JCAE added $13-million to the authorization bill for three small pressurized-water reactors in the Antarctic (NU, Apr. '60, 27). The Navy, for which the plants would be supplied, says it has an early need for two 1,500-kwe reactors at McMurdo Sound and one 800-kwe at Byrd Station. The $13-million item would pay for these three and—if AEC, in ordering them in duplicate, reduces significantly the estimated $4-million-plus cost—there might be enough in the authorization to fund a fourth, 500-kwe reactor at the South Pole.

Authorizing funds to AEC for "field" stations of the military is unusual and the Bureau of the Budget has made it clear that it does not support this approach to getting them built; it wants the Navy to put up the money. However, the Navy has said it wants the reactors (if AEC pays for them), and—unless the Budget Bureau attempts to block the program—AEC is expected to go out with a bid invitation soon after Congress actually appropriates the $13-million authorized by JCAE.

Alco Products and Martin Co. have been in the forefront of stationary-re-

Announcement of a New Publication—Nucleonics Week

The McGraw-Hill Publishing Company is pleased to announce a new publishing service for the nucleonics field—Nucleonics Week, a weekly newsletter supplementing the monthly news coverage offered by Nucleonics magazine. Regular publication of Nucleonics Week will begin on April 28, 1960.

Why Nucleonics Week now? Although the regular news section of Nucleonics has always been very favorably received by our subscribers, many have expressed the need for a more frequent service. In these next several years, as the industry begins its growth, interest in new developments will be great, competition for contracts will be severe and knowledge of government and Congressional policies and actions will be important.

Publication schedule and format. Nucleonics Week is six pages in length and is printed by the photo offset process. The final closing time for copy is Tuesday morning. It will be mailed to subscribers on Tuesday afternoon of each week.

Content and character. Nucleonics Week is written in newsletter style—short articles intended for fast reading. The subject coverage will be similar to that of the regular news section of Nucleonics. But a much greater effort is being placed on developing behind-the-scenes news.

Relationship to Nucleonics. The news section of Nucleonics will be basically unchanged. The emphasis in Nucleonics' monthly news coverage will continue to be placed on stories in depth, of a length and character that cannot be accommodated in the newsletter. Thus both Nucleonics and Nucleonics Week will be needed by those who are actively involved in the nuclear field.

Staff. Nucleonics Week will be prepared by the news staff of Nucleonics augmented by additional personnel. Also, the world-wide news bureaus of McGraw-Hill will be used to an even greater extent to give subscribers the benefit of the best nuclear reporting team in the world.

Subscription information. Nucleonics Week will only be available to those who are either currently subscribers to Nucleonics or who become subscribers to Nucleonics simultaneously with subscribing to Nucleonics Week. The subscription rates for subscribers are: $75 per year in North America, $90 per year in all other countries (this includes the cost of airmail service).

For further details on Nucleonics Week and to obtain a sample copy, please write to Jerome D. Luntz, Publisher, Nucleonics Week, 330 W. 42nd St., New York 36, N. Y.

actor development for military use but at least four other reactor manufacturers have said they are interested in bidding—Allis-Chalmers, AMF Atomics, General Electric and Westinghouse.

Kaiser Study

A study of the power economics at McMurdo Sound and ten other military sites—conducted by Kaiser Engineers—showed that a 5-Mwe, pressurized-water reactor at McMurdo would save the Navy $21,580,000 over a 20-year plant life. Kaiser is supplementing this study with cost analysis for Byrd Station and the Pole and this report was due at JCAE by May 1.

For the other nine sites in the original report, Kaiser reported the following savings (or losses) over a 20-year plant life if nuclear stations were selected over conventional stations: Okinawa, $8,488,000 on a 40-Mwe boiling-water reactor; Guam, $430,000 on a 20-Mwe BWR; Thule AFB, $31,838,000 for a 25-Mwe BWR; Camp Carson, ($12,076,000 loss) on a 7-Mwe PWR; Asmara, ($7,435,000 loss) for a 5-Mwe PWR; a classified underground site, ($7,407,000 loss) on a 5-Mwe PWR; a classified Nike-Zeus site ($5,766,000 loss) on a 10-Mwe PWR; Inchon, Korea, ($7,325,000 loss) on a 10-Mwe PWR; and a barge in the Atlantic area ($5,104,000 loss) on a 20-Mwe PWR.

Other JCAE Additions

In addition to the $13-million Antarctica authorization, JCAE also tacked onto the bill on its own initiative $5.6-million for a materials-research lab at the Univ. of Illinois, $2.2-million for a radiation lab at the Univ. of Notre Dame, and $1-million for facilities to increase research on the bio-medical aspects of radioactive fallout (the extra $1-million raises this item in the bill to $5-million). JCAE also requested AEC to schedule design studies on a power reactor of the steam-cooled type and mobile facilities for food irradiation; reports to JCAE on these are due next Apr. 1.

At AEC's request, JCAE also increased the authorization for improvement of two high-energy accelerators —raising to $10,820,000 the $1,350,000 request for the Princeton-Penn accelerator, and raising to $9,600,000 the $1,100,000 request for Lawrence Radiation Laboratory's Bevatron (Berkeley).

As expected to be approved by the House and Senate before the month was out, the bill also includes $165-million in other capital equipment for '61 (NU, March '60, 23). Meanwhile, the House Appropriations Committee began hearings on both construction and operating budgets of AEC late last month.

Navy Core Fabricators Feeling Pinch; No Early Relief Seen

The Navy core business is hanging on the ropes. But none of the five companies making fuel element assemblies for nuclear-propelled naval vessels is about to give up and get out of the business—although each might have incentives to do so.

In a nutshell, the problem is a starkly simple one—a classic situation in economics: overcapacity, following a falling-off in demand. (That this underdemand is more the fault of the present Administration's fiscal policies—and of their enforcer, the Bureau of the Budget, and less that of the Navy itself, does nothing to help those impaled on the horns of the problem.)

And so it is that the five companies who tooled up at their own corporate expense for a level of business expected in 1957—at a total cost known to be more than $15-million, probably closer to $20–25-million—are now left stranded high and dry as the tide of expanding naval construction ebbed to a relative trickle.

Because of overcapacity, price-cutting has set in, as it usually does. Some companies are ready to produce at a certain loss, just to justify keeping their skilled labor forces together.

A further depressant has been the rapid improvement in core life, which has reduced considerably the market for reload cores.

Early Hopes

In 1957, high-water mark of hopes for an expanding—and acceleratedly expanding—nuclear navy, five companies tooled up to be able to produce about 50 (if needed, 60) cores a year. Annual capacity of each of the five is now believed to be: Babcock & Wilcox, Lynchburg, Va., 8; Combustion Engineering, Windsor, Conn., 8; Westinghouse Atomic Fuel dept., Cheswick, Pa., 10; Olin-Matheson, New Haven, Conn., 12; M&C Nuclear, Attleboro, Mass., 12.

In the spring of 1957, Vice (then Rear) Admiral H. G. Rickover, head of NRB, told the Joint Committee on Atomic Energy about the procurement of naval reactor cores and other components, and the development of a supplying industry:

"The next important thing we had to do [after assuring zirconium supply] was to get more facilities for making reactor cores. Our practice right now is to have our laboratories develop and make the first core of a type, and thereafter to put it out on competitive bidding . . . We now have a number of companies that have equipped themselves at their own expense to manufacture cores on a competitive basis . . . Each company has put in at least $3-million of their own money, with no certificate of necessity, for the necessary facilities. They have taken contracts for these cores on a competitive basis. On this basis we were able to order these cores for less cost . . . "

REP. HOLIFIELD: Do you have any troubles getting private companies to bid on these different components?

ADM. RICKOVER: Not on reactor cores . . . We are trying to get this program into industry as fast as possible—to buy it like a loaf of bread.

REP. PATTERSON: You could not expect any manufacturer to put special gear into a plant where he is going to make only 200 or 300 or probably even two.

RICKOVER: Yes, sir; I do.

PATTERSON: You expect him to do that?

RICKOVER: Yes, sir.

PATTERSON: And have them pay for the tooling?

RICKOVER: Yes, sir. Sure. Why not?

REP. PRICE: Are they doing it extensively?

RICKOVER: Yes, they are.

HOLIFIELD: Do they do it at a loss to themselves?

Six More S5W Sub Reactors

Under a Polaris speedup plan proposed by the Defense Dept. and approved by the President, six more S5W submarine reactors would be ordered for as many Polaris-firing subs—traded against two of three attack submarines, also in the fiscal-'61 budget: net gain, four. The proposed '61 budget would now contain three fully-funded missile subs plus procurement of longlead-time reactor parts for nine more—plus one remaining *Skipjack*-type attack sub. Total Polaris subs authorized would rise to 21.

RICKOVER: Look, next year we are going to have about $50-million worth of reactor core business alone. It is like a fuel business. Once you get a ship in the water with a core you have got it there three or four years, then you have to take the core out and put a new one in. It is like the oil business . . .

Lost: 40 Carrier Cores

The $50-million worth of reactor core business Admiral Rickover said would materialize in 1958 was presumably based on the fact that in addition to submarine cores, eight A2W cores for the carrier *Enterprise* were to be ordered that year: some $32-million alone, at then-current prices. In 1957 the Navy planned to build five sisterships to *Enterprise*, one a year: a total of six carriers, requiring eight cores each, over six years.

But it was not to be. The budget-parers and the enemies in Congress of the carrier ship-type (who contend, rightly or wrongly, that the carrier is outdated) double-teamed the Navy's nuclear carrier fleet plan, and *Enterprise*, now being readied for September launching, is still one-of-a-kind.

A similar fate overtook expansion of the nuclear submarine building program. Despite the demonstrated and proven value of craft like *Nautilus*, *Skate* and *Skipjack*, budget considerations have prevented attainment of the Navy's hoped-for buildup, at a rate of 12 or more a year, to fleets of 75 *Skipjack* attack-type, and 40–50 Polaris-firing submarines. In fiscal-59, thanks to a supplemental appropriation bill, a record 11 nuclear subs were authorized, but in fiscal-'60 the number dropped to four, lowest since fiscal-'55. The fiscal-'61 program is undergoing some upward revision as this is written (*see p. 20*).

Famine for Fuel Fabricators

This is why the lean years set in for the core manufacturers. Far from averaging ten cores/yr each, they are now lucky if they can divide up a total business of ten cores a year—that is, if they can average two a year.

Then the famine began to spiral—to feed on itself, so to speak—as companies got hungrier, competition keener, prices lower. For instance one company contracted early in 1957 for the first post-developmental S5W core at $4.5-million. It lost money—although it did learn the tricks of making the S5W core efficiently. Last year a competitor "bought" two S5W orders for less than $2-million each. Next time around the first company bid less than $1-million each to build a pair of S5Ws, which it could now build for perhaps $2.25-million each. Thus it has voluntarily taken a loss of $1.5-million per core, $3-million total, just to keep busy.

Consequently there might well have been some perplexity on the part of industry when it heard Admiral Rickover tell the Joint Committee recently: "I understand most of the companies who are making cores for us are now in the black to the extent that they are beginning to make money now. I don't believe any of them have fully recovered the cost of their investments, but they are not losing money any more."

The economic history of the A1W-type (carrier and cruiser) core has followed the same pattern. The first ones were made for $4-million; the going price now is about $2-million plus.

In Admiral Rickover's words, "The cost of cores has decreased about 40% or so in the last two years. Furthermore, the life we are getting out of the cores has gone up about 70%. Roughly, there is a reduction per usage of about three to one. It has gone down about three times if you figure the cost per kilowatt-hour or unit of energy out of the core . . .

"For example, in the *Skipjack*-type submarine, the cost has gone down to about 30 or 40% of the original one. The life with a new core we are putting in will go up about 70%."

Having costs go down 40 or 60 or 70%, having a number of vendors falling over each other to be of service, would ordinarily leave the purchaser happy. But industry gives NRB credit for being perplexed and uneasy about the situation. For obviously if disappointment were to turn to despair in epidemic proportions and most core manufacturers gave up at the same time, it would be disastrous to the naval reactors program.

"Each of the core makers has very good reasons for staying in," said an official of one of them. "But if they bleed too much, they might change their minds."

In practice, three of the five manufacturers have been garnering the preponderant part of the orders—M&C Nuclear, Olin Matheson and Westinghouse. Yet one of the companies in the minority points out that there has been no attempt to "pull any strings"—that this is the result of the prices bid, in the play of the marketplace. The three firms that captured most of the business simply bid lowest. If two firms bid the same, it was suggested, NRB might try to help the one in the worse situation, but could do this probably only if the price spread were not greater than about 0.5%.

As a matter of fact, Admiral Rickover is reported to have made one about-face to try to help his core makers: where he once insisted that a naval core fabrication facility be used exclusively for Navy work, he is now said to encourage the fabricators to try to obtain commercial work.

But this has not yet materialized, and the firms' unique capability in fuel fabrication development—a potentially great source of strength to the U. S.' nuclear power program generally—is nearly idle. The firms feel that they could contribute to the fuel cycle program, taking basic data developed in the national laboratories, and working on fabrication development. They point out, too, that if the government wants to rely on utilizing industry skills, a bad precedent set here might affect the readiness of industry in

Navy Core Assignments Thus Far

*Core type**	*B&W*	*Comb. Eng.*	*M&C Nuclear*	*Olin*	*Westinghouse Cheswick*	*Westinghouse Bettis*	*KAPL*
S1W-S2W	2					5	
S1G-S2G							2
S3W-S4W	1	4			3	1	
S3G-S4G			4½				
S1C-S2C	1	2					
C1W-A1W-A2W			2	4	4	2	
D1G-D2G				3			
S5W	4	2	4	7	3	1	
Annual capability†	*8*	*8*	*12*	*12*	*10*		

* To match core- and reactor-types with individual ships, see table in NU, Sept. '59, 74.
† Expressed in terms of submarine cores. The C1W-A1W-A2W large surface ship reactor core is the equivalent of about 1½–2 submarine cores.

future to invest its own money in similar projects.

Not only has the number of cores ordered turned out to be less than one-quarter of what the industry expected, not only have the rapidly-falling prices cut the total dollar volume in half again, but in addition the replacement business is obviously going to be cut 70% if the core life is increased by 70%. This helps explain why the core makers are not optimistic about an improvement in the situation for at least a year or two.

What are they doing about it? "We are trying to improve our efficiency as rapidly as we possibly can," offers one. "We are trying to operate on a survival basis, in the hope of some pick-up, especially when the Polaris missile subs have shown they are as good as they can be."

How can one forecast at least short-term core demand? Watch the ship construction schedules. It takes 2½ years to build a submarine, only one year to build a core—but no nuclear sub has ever had to wait for fuel. So it can be reliably estimated that core orders will be signed about 1½ years before a sub is completed and ready to begin nuclear testing of her primary loop.

As for long-term forecasting: the situation is much too dependent on a non-technical, non-economic intangible: the unpredictable mood of Congress and the Administration, and their interplay. But there is an optimistic promise held out by Admiral Rickover, in his testimony before JCAE earlier this year:

"We currently have under contract with industry about $200-million for nuclear cores . . . " [This backlog is quite unevenly spread: Combustion is reportedly ready to ship out its last core; Olin has just recently shipped its first one after considerable delay, and has a huge backlog.] " . . . We expect within the next five years to order an additional $140- to $150-million for nuclear cores and the same amount for replacement cores."

This total of $280–300-million over five years would mean $56–60-million per year if spent at an even rate, significantly more than was committed last year. It may be, however that Admiral Rickover is also counting on expansion of the Polaris submarine program, and has in mind a gradual increase in annual core orders, with the bulk of $300-million being spent in the latter part of the five-year period. If so, it would be a considerable improvement over the core makers' present plight. But the Admiral isn't saying.

PWR critical again with Core-1, Seed-2

PWR at Shippingport went critical again April 12 with the second set of seed elements in its first core (NU, Dec. '59, 22; April '60, 21). Rod worth and other physics tests as well as complete plant checkout are being run, and full power was expected to be reached by April 23 or 24, but a problem with feedwater heaters may delay that somewhat. Seed 2 is expected to deliver as much as 60 Mwe.

USPHS to increase activities on radiological health

The Administration has decided to reorganize the U. S. Public Health Service to create a new Bureau of Environmental Health, with particular emphasis on research on and control of radiation in air and water. USPHS now has three bureaus—State Services, Medical Services and National Institutes of Health (cancer, heart disease, etc.); the new Environmental Health bureau is expected eventually to reach the size of the NIH group, whose annual budget is more than $400-million. The new Bureau would absorb the present Radiological Health div. (*see page 23*) and bring a major acceleration of the Division's efforts to learn more about the sources of radiation (including reactors, etc.) and effect of radiation on man.

AIF rejects EJC bid for joint backing of one trade fair

The Atomic Industrial Forum last month turned down a proposal from the Engineers Joint Council that the two groups drop their plans for separate trade fairs in 1961 and get together with the American Nuclear Society for one big show and meeting in 1962 and beyond. EJC has had a show scheduled for the '61 Nuclear Congress in Chicago next spring. AIF, on the other hand, will resume its AtomFair in December of this year in San Francisco and has scheduled the next AtomFair for late in 1961, also in Chicago. EJC, in effect, had proposed a truce for '61: both associations would have called off '61 exhibitions and negotiated joint sponsorship of one annual show thereafter. AIF's rejection of the idea left EJC with the choice of proceeding with its spring show or dropping it; there were signs late in the month that it would be cancelled.

Mainhardt, Biehl leave AGN to create own firm

Two key executives of Aerojet General Nucleonics have left AGN to form their own firm—M. B. Associates. They are Robert Mainhardt and Arthur T. Biehl, respectively, vice-president and general manager at AGN. M. B. Associates has been headquartered at Danville, Calif., near AGN headquarters at San Ramon. It is offering consultant service on fission and fusion, emphasizing advanced technology, but will not limit itself to reactors. Chandler C. Ross, AGN vice-president for engineering, has succeeded Biehl.

Dresden on line, expected to go to half power

Dresden began delivering electricity to the Chicago area late last month, reaching 64 Mwe on Apr. 18 and expecting to reach its legal, half-power limit (90 Mwe) before month's end. AEC hearing on a full-power license for Dresden is scheduled May 4.

AEC reduces access-permit categories from 27 to 2

AEC has reduced its access-permit program to two categories: nuclear technology and plutonium production (down from 27).

Nuclear-Instrument Trade Assn. Continues to be Elusive

An attempt by the Electronic Industries Assn. to form a strong nuclear-instrument trade association has met with an unenthusiastic response by the industry. This was the report from EIA in Washington following a recent suggestion by officials of the Radiological Health div. of the U. S. Public Health Service that such a trade association was needed.

The 20-month-old USPHS division considers itself both a growing customer for nuclear instrumentation and an influential force in the future acquisition of instrumentation by state and local health officials. Division officials called for an association with which they could deal in the procurement, standardization and development of such equipment.

"We need an association to deal with so we can present our problems to the industry and not selectively encourage one firm over another," a Division official explained to NUCLEONICS. " . . . Eventually this will be a pretty good sized program of equipment purchase."

A Slow Start at EIA

EIA officials, reporting on the reluctance of industry manufacturers to join its year-old Nuclear Instrumentation Section, said the poor showing was forcing them to relegate the group to the status of a subsection within a new section on all types of instrumentation. Only seven firms have joined the Nuclear Instrumentation group, they said—only one is a so-called independent specializing in this type of equipment.

Present membership: Anton Electronics Laboratories; Bendix Aviation Corp. (Cincinnati div.); Collins Radio Co.; RCA Service Co.; Tung-Sol Electric Co. (Chatham Electronics div.); Westinghouse Electric Corp. (Power & Nuclear Control Engineering Assembled Switchgear & Devices dept.); and Hughes Aircraft Corp. (Nuclear Electronics Laboratory).

The Section was established last spring under the leadership of Nicholas Anton, president of Anton Labs. It was decided then to request affiliation with EIA to avoid the formidable expense of creating a staff and establishing offices for an independent group. Section meetings have been attended by representatives of non-EIA members, according to Anton, but formal membership has failed to build up.

The present attempt to form an association is only the most recent of several earlier failures. The first, established ten years ago, was fairly successful but declined when the group associated itself with the predecessor of EIA. Abortive efforts have since been made via the Atomic Industrial Forum and on an independent basis.

Forum Again Active

Officials of the Atomic Industrial Forum said they have recently talked with radiation-industry executives and officials of the Public Health Service about the trade-association situation. With the prompting of Ernest Wakefield, president of Radiation Counter Laboratories, and others with a strong interest in seeing an association developed, the Forum is considering stepping up its activities in the gathering of industry statistics and in the working out of standards.

The Forum also considers itself in a position to help government agencies circularize the radiation industry on procurement of equipment.

Industry Officials Comment

All but one of several industry officials queried by NUCLEONICS—most non-EIA members—said they favored creation of a strong association. It was the majority opinion, however, that it was not worth the effort unless the body were an independent one, representing nucleonics firms only. Obstacles described by these executives ranged from suspicions among competitors of each other, to the sheer independence of firms in the business and to the expense of such an organization. Some comments on both the association idea and on dealing with the government via an association:

Samuel Auchincloss, Tracerlab: "I don't see why anybody in a red-blooded, competitive industry should do it this way [deal with the government via an association]. I don't think we ought to do it." He said it was tantamount to asking "a group of rugged industrialists" to give up development of unique products in favor of manufacturing the same products. He also warned that it could get the industry into antitrust trouble.

John Kuranz, Nuclear-Chicago: "There is a great need for such a group in the industry—a good, strong association. All of us understand why it's needed but we can't get together. It has to be started up by a respected organization or someone with no ties to the industry in whom the industry can have confidence."

Irving Zimet, Victoreen: "Victoreen would like to see one and participate in one. It would not like to see one which is a sales football—where much of the information exchanged in meetings is used by your competitors."

Don Collins, Landsverk: "EIA is not the proper group to represent our industry. We need our own group. When I look at the expense of joining EIA I can't see where any of us would get value received." He said Landsverk generally preferred to deal with government customers directly but that an association would be helpful where there were problem agencies. He summed up: "The industry doesn't pull together enough to have an independent nuclear group—and none of the existing groups really represent us."

What is the Radiological Health Division?

USPHS' Radiological Health div., established July 1, 1958, has a far-reaching mandate on behalf of the federal government: to develop data on radioactivity in air and water, from whatever source, and to relate this to the public health—its effect on man. Under Francis Weber, the division staff has grown from less than 100 in fiscal year 1959 to 171 this year and funds are sought in the '61 budget to increase it to 362. Radiological labs have been established in Las Vegas, Nev. and Montgomery, Ala., and a third staff group will be located in Montgomery County, Md. The division's budget has increased from $660,000 in '59 to about $3-million this year to a proposed $6.3-million in '61.

It has pending in Congress a request of $350,000 for advance procurement of equipment—most of it radiation instrumentation—to equip its growing staff. In its operations it will work closely with state and local officials interested in establishing their own radiological-health programs—giving them both training and advice.

Space Flight with Nuclear Power Moving into Foreground

Space travel with nuclear power—for both power and auxiliary use—made significant advances last month after a number of separate developments on various fronts in the race to space. Here are nine:

1. Shippingport into Orbit? Perhaps most interesting development was Westinghouse's prediction that by 1970 it would be able to lift into orbit an auxiliary power plant of 60 Mwe—the output of Shippingport. John W. Simpson, Westinghouse vice president for atomic power and head of its Astronuclear Lab, told the opening session of the Nuclear Congress that in ten years it would be possible to build a 60-Mwe nuclear power plant weighing only 120 tons—4 lb/kw. (SNAP-2 weighs about 210 lb/kw.) This would require a fast reactor, stripped of all expendable components and pushing temperatures to the highest that known materials can stand. This in turn means ceramic fuel and a closed-cycle reactor-turbine-pump loop using a coolant such as molten or boiling sodium—eliminating heat exchangers, valves, etc. Simpson feels that the demand for auxiliary power in space has not yet been sufficiently realized.

Simpson's Astronuclear group believes it can build a 1-Mwe plant by 1965, a 10-Mwe by 1967—and that it can achieve an 8 lb/kw plant weight with today's technology. It is already at work on the materials and systems problems involved.

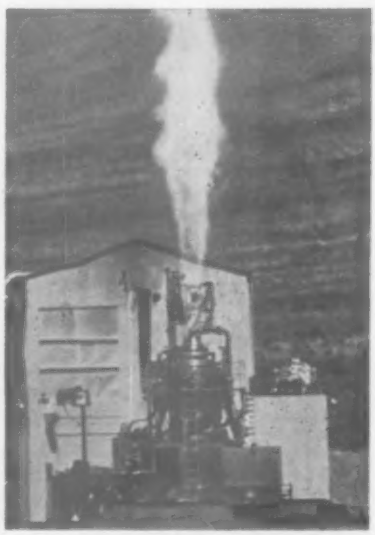
2. Nuclear Rocket Portrait. Edwards Air Force Base, acting as nuclear rocket center for the Air Force, quietly issued an invitation to bid on making a broad study: what a nuclear rocket will be like, what is now available and what is likely to be, what this means to the Air Force in terms of its mission analyses. Every firm having any interest at all in nuclear space power is reported to have bid.

Flight-test for Rover

3. Rover Flight-test Program. NASA promises to have invitations out in a month or two on a 6–9 months' study of a flight-test program, in support of the Rover (nuclear rocket) project. Following the success of last summer's test of Kiwi-A (NU, Aug. '59, 23), the Rover project is now in position to start serious work on the problems of launching a flight test vehicle. (Kiwi is of course not a flight prototype but a materials and fuel test.) The study will cover desirability of surface launch vs space launch; control, startup and radiation-level problems; shock dynamics; site location; consequences of failure; reentry. Result of the study will be a flight-test program for a rocket such as the Rover project might produce.

4. Kiwi-A3. Los Alamos Scientific Lab is building not one, but two successors to Kiwi-A: in addition to Kiwi-A Prime (NU, March '60, 29), it is building Kiwi-A3. The two are nearly identical, and "outwardly similar" to Kiwi-A, now reassembled without core for use as a mockup for cold flow experiments in preparation for tests this summer on the two new Kiwis. Kiwi-A Prime is already being assembled at Los Alamos and will undergo cold critical tests there before shipment to the Jackass Flats, Nev., test site. Power operation is to start in midsummer; Kiwi-A3 tests will start shortly after A Prime tests are completed. Kiwi-A3 will be tested to failure ("until there is positive evidence of damage to the reactor") to determine safety margins and performance limits. At Jackass Flats, construction has begun on a second test cell, similar to the first but permitting more extensive exploratory testing of complete rocket engines.

5. Quadruple Power at Half Cost. The virtue of combination chemical-nuclear space vehicles was pointed out to the American Power Conference in Chicago by Lt. Col. Howard R. Schmidt, USAF, of AEC. Replacing the third, fourth and fifth chemical stages of the Saturn space vehicle now under development with one nuclear stage—a 2-Mw reactor—would double the payload from 9,000 to 18,000 lb, Schmidt said. Then replacing the second stage also, by an 8-Mw reactor, would quadruple the payload, to 36,000 lb. Yet such a combination vehicle would cost but $24-million (including an estimated $10-million for the two reactors) as against $48-million for the all-chemical, also-36,000-lb-payload Nova that is planned as next step after Saturn. The combination vehicle could be operational within 15 years.



KIWI A operating last summer: flame is hydrogen propellant being burned off

Case for Nuclear Rocket

6. A window on the future of nuclear power in space was opened at the Joint Committee on Atomic Energy hearings on "Frontiers in Atomic Research." Krafft Ehricke of General Dynamics (Convair) and Raemer Schreiber of Los Alamos outlined the case for nuclear space propulsion. The gist of it (as Ehricke put it): "Space will be conquered only by manned nuclear-powered vehicles. Planning anything else for the late '60s is flirting with obsolescence almost from the start . . . The surest way to cripple the U. S. space capability of the '70s is to cripple its nuclear engine development now . . . We should not hesitate to proceed doing right away what eventually we will have to do anyway."

7. SNAP-8 Turbine to Aerojet. The $8-million job of building the power-generating system for Atomics International's SNAP-8 (30-kwe scale-up of the 3-kwe SNAP-2) went to Aerojet-General, chosen from among eight bidders. SNAP-8 should be operational in five years, could also serve as power source for an ion-propulsion engine. Since the SNAP-8 reactor output will allow generation of 60 kwe, there will also be a dual version with one reactor and two sets of conversion machinery, making a 60-kwe package of 3,000 lb (50 lb/kw).

8. Uses for SNAP. At the JCAE "Frontiers" hearing, some uses for SNAP power beyond instrumentation and telemetering were outlined by J. R. Wetch of Atomics International. They include: reliable low-cost all-weather intercontinental telephone systems; all-weather worldwide FM broadcasting; continuous global telecasting; precise air-traffic control; navigational aids; and weather surveying.

AEC Compliance Div. Delayed, Will Soon Inspect All Licensees

A little of the confusion over AEC's inspection operation was cleared up last month by William F. Finan, the Commission's new assistant general manager for regulation and safety. AEC had made the internal decision, before Finan came on the job in December, to establish a new Compliance div. and shift the inspection of licensees to this new division. Six months later, however, the Compliance div. is still a paper one.

In an interview with NUCLEONICS, Finan explained that staffing of the division was being held up until a director can be named. When it is formed, he said, it will assume responsibility for the safety inspection of all licensees of the Commission, including the 8,000 holders of radioisotope-use licenses and the reactor, critical-assembly, special-nuclear and source-material licensees.

The Inspection div., which is one of only three AEC groups specifically created by the 1954 Atomic Energy Act, will continue to concern itself with AEC and contractor activities, reporting directly to General Manager A. D. Luedecke, Finan said.

Dual Functions and ACRS

Finan also had a little to say about two areas of nuclear-safety of particular interest at this time: the question of separation of AEC's regulatory and promotional functions; and the status of the Advisory Committee on Reactor Safeguards.

On the first point, he said there was no basis for speculation that a separate agency might be established in the foreseeable future. "It has never been a part of my understanding—now or at the time I accepted this job—that it would involve setting up a regulatory group separate and physically apart from the promotional and developmental activities of the Commission," Finan said.

The difficulty of staffing two separate agencies with competent personnel, plus the problem of coordinating research activities on safety ("These are matters on which my people are constantly consulted by all the other divisions in the Commission"), makes a physical split in the staff highly inopportune, he believes. A man who has dealt with management of the atomic energy program in his former post as director for management and organization at the Budget Bureau, Finan commented:

"From the management point of view, it would only mean that the President—overburdened as he is—would repeatedly be called on to coordinate the activities of the two separate bodies. This is, of course, the same type of problem which necessitated creation of a single Federal Radiation Council to coordinate the radiation standards problem which existed between all the government agencies."

Role of ACRS

The ACRS role in reactor safety has been an uneasy one—as between it and the Commission—since the Price-Anderson Indemnity Act was amended to make ACRS statutory; that is, a body created by Congress to review reactor safety. AEC has its own staff for this job. Are both of these safety groups responsible to AEC? Or is ACRS, from a practical point of view, responsible to the Congress and—through it—to the public? Since its advice to AEC must be made public—also by amendment of Price-Anderson—is the practical effect of this to make it an independent body whose "advice" AEC cannot reject? These questions are some of those asked by people at both AEC and ACRS.

Finan indicated, without taking sides as to the necessity for having the body, that he was one of those not clear as to ACRS' status.

"In addition to convincing the AEC licensing and regulation staff and then, later, a hearing examiner, that their project is safe," he said, "a group that wants to construct a sizeable reactor also has to convince the part-time body of experts who look at the matter through different eyes [ACRS]. This means that the project—if approved—is not any safer than it was all along. It means the project has been additionally checked and this time by technicians with a pedigree."

On the other hand, he said, the ACRS review lends to the regulatory process a greater degree of assurance than merely "institutionalized approval."

"The ones who are politically accountable to the people want ACRS," Finan could only conclude.

AEC Issues Two Permanent Indemnity Rules . . .

AEC last month issued two important permanent regulations on reactor liability under the Price-Anderson Act; they become effective May 7. The first spells out the financial protection required of a reactor licensee, according to reactor size and population density; it also provides $500-million government indemnity above the financial protection required. The second approves the liability-insurance policy forms proposed by the Nuclear Energy Liability Insurance Assn. and Mutual Atomic Energy Liability Underwriters.

Also published by AEC was a proposed regulation describing the general forms of agreement to be entered into between AEC and reactor licensees required to have financial protection (federal and nonprofit educational licensees are exempt from the financial protection requirements).

. . . and Calls Attention to Possible On-site "Gap"

AEC officials let it be known last month that enactment of an amendment to the Price-Anderson indemnity law—which the Commission itself is sponsoring—raises the possibility of a "gap" in reactor insurance coverage. The situation is this: Price-Anderson as it now stands could be construed as providing liability coverage for on-site property (for example, liability for damage to the reactor). However, AEC lawyers feel, the Act is not intended to cover on-site property; such coverage, they contend, would simply dilute the $500-million available under the Act for off-site liability. Thus, AEC is pushing its request that Price-Anderson be amended to exclude on-site liability.

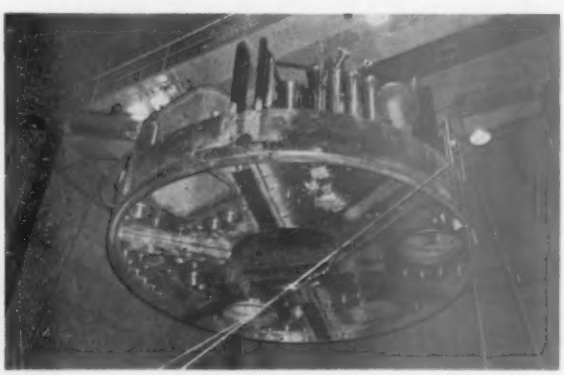
On-site property insurance is available from the insurance industry in the amount of about $60-million. However, complete destruction of a $100-million reactor would create a "gap" of $40-million. On the $60-million that is available, the insurance companies have waived their right of subrogation (suit against any supplier); but the suppliers could be hit by suits for damage over $60-million. AEC officials do not regard the situation as serious, rather "something that ought to be thought about."

IN THE IDAHO DESERT, Argonne's Idaho group last month finished installing EBR-2's primary tank, marking 85%-completion of gross construction (excluding nuclear systems) of the reactor plant (power is 93% complete). The 16.5-Mwe EBR-2, last of the five reactors in the 1954 Five Year Program, is—with the 100-Mwe Fermi fast breeder—a keystone in the U. S.'s breeder development program. It is aiming for December criticality.

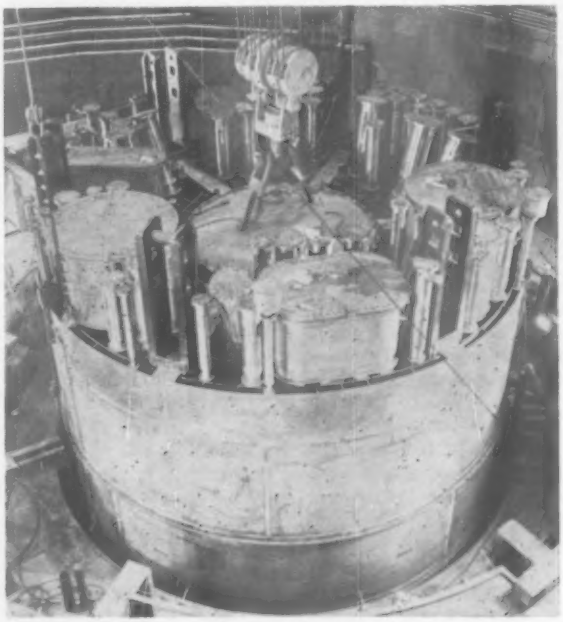
Experimental Breeder Reactor No. 2 Drives to Completion

1 Half of the primary tank cover arrives on site. A unique design feature of EBR-2, the 26-ft-dia, 30-ft-deep tank houses not only the core but the entire primary system

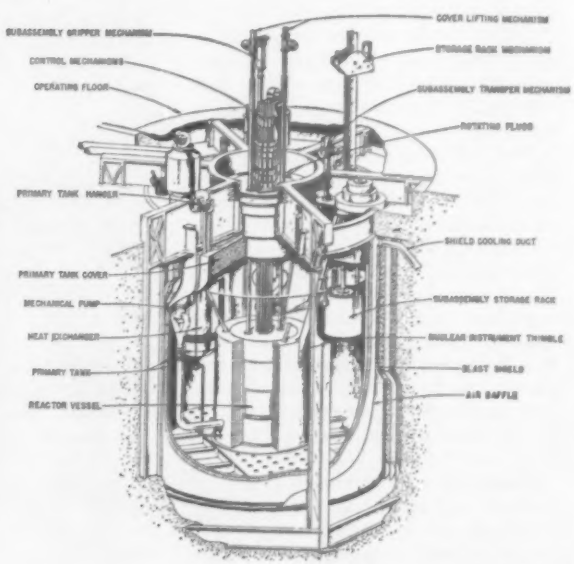
2 Primary tank outer vessel is lowered into the cavity. It will be hung from top to allow trilateral thermal expansion



3 Primary tank cover, its two halves reassembled, poised above inner tank prior to being lowered and seated on it



4 Complete primary tank assembly, including cover, inner and outer vessels, being raised out of tank cavity for installation of thermal insulation on exterior surface. Isometric sketch (below) shows relative position of parts



REACTOR NEWS

BAD MONTH FOR RESEARCH, TEST REACTORS

Two U. S. research or test reactors ran into trouble last month: 1. At the Westinghouse Test Reactor there was evidence one or more (but probably not more than three) fuel elements had ruptured. Monitors in the head tank and surge tank gave the first warning; in some places readings reached 4–6 r. But no activity got beyond the property and not one employee was over-exposed: none received so much as a week's dose. The reactor staff does not yet know exactly what happened as beta activity on the shroud of the pressure-vessel head has delayed its removal. Decontamination was proceeding as this went to press.

WTR had already operated about 15 days at 40–45-Mw in moving up from the original 20-Mw to the newly-authorized 60-Mw power level. But at the time of the accident it was actually going down in power, after having run for a while at 30–40 Mw.

2. West Berlin's U. S.-built "teakettle" (water-boiler, or solution-type) research reactor broke down. The 50-kw Atomics International unit halted operations when a welded metal piece came loose inside the catalyst chamber and stopped the gas flow. The reactor will have to be taken apart and the highly radioactive chamber cut open. Experts from the Berlin branch of Pintsch-Bamag agreed to tackle the repair job.

GE RADIATION MEN EXPOSED AT TWO SITES

General Electric technicians in radiation atmospheres were recovering from overexposures last week. At Vallecitos, a technician preparing a spent—and deliberately ruptured—GETR fuel element for transfer from the storage pool to the active materials lab inhaled tracer amounts of radioiodine in excess of permissible limits, but said to be 1/500th of the amount used in thyroid therapy. And at Lockport, N. Y., nine GE employees got too close to an unshielded klystron microwave tube at an Air Force electronics lab and some got over 100 r partial-body dose (they were protected by the lower part of the shield). Three were sent home, three were discharged, and three are recovering from the usual effects of radiation sickness from this nonnuclear source.

THREE REACTOR SITES UPSET

The process-heat reactor group gave up on the Pt. Loma, Calif., site (NU, April '60, 30); the AEC–Interior Dept. team planning the nuclear plant to desalinize seawater is considering its next move. It has a number of alternate sites in Southern California and is assigning priorities to them on a crash basis. . . . A Hawaii circuit court judge has denied Hawaii Electric Co.'s application to condemn a 485-acre site for a nuclear power plant (NU, Jan. '58, 25), climaxing a 2½-year court fight. . . . And the site proposed by Jamestown, N. Y., for the Small-size Pressurized Water Reactor (NU, Feb. '60, 17) was ruled too close to a densely-populated center by both the Advisory Committee on Reactor Safeguards and AEC's Hazards Evaluation Branch.

PRESSURE SUPPRESSION: MORE STUDY BY PG&E

Pacific Gas & Electric asked postponement of hearings on a construction permit for its Humboldt Bay reactor in the light of a report by the Advisory Committee on Reactor Safeguards. ACRS had found that the reactor design was "adequate" for the chosen site with conventional pressure-vessel containment, but that "the information so far provided does not demonstrate the suitability" of pressure suppression. "Further tests are necessary," ACRS decreed. Thereupon, PG&E president Norman R. Sutherland told NUCLEONICS, "we elected not to revise our form of application to the conventional form of containment. Instead we want to carry out the tests suggested by ACRS on pressure suppression, because we think there is merit in our plan." PG&E will spend another $100,000 on the tests, which will involve building one of 48 segments, full-scale, of the pressure-suppression chamber and testing it with steam. Sutherland says the work will throw Humboldt Bay back four months: one to build the facility, two to test, one to evaluate results.

AEC REPORT ON TANKER REACTORS FILED

The report the Joint Committee on Atomic Energy asked AEC to file by April 1, on three design studies for a reactor to drive a 43,000 dwt ton tanker, came out: direct cycle boiling (General Electric) reactor, $22.3-million capital cost, $3.8-million operating cost/yr; pressurized water (Combustion), $23.2- and $4.07-million; indirect cycle boiling (Westinghouse), $24.4- and $4.01-million; conventional plant, $17.3- and $3.3-million. The net effect of the report, plus lack of enthusiasm on the part of influential members of the Joint Committee on Atomic Energy and the fact that the Administration is taking no favorable position, makes it obvious that the long-hoped-for second U. S. nuclear merchant ship, a tanker, will not be voted this year.

TOWER SHIELDING REACTOR NO. 2 CRITICAL

The second research reactor suspended from the tower shield facility at Oak Ridge went critical March 26. TSR-2 replaces the similar but less powerful TSR-1 which was shut down in December 1958 and dismantled because it could no longer fill the need for high neutron-flux emission in all directions. TSR-2 has a 5-Mwth maximum power level, compared with TSR-1's 500-kwth. The $1-million tank-type heterogeneous reactor will be suspended as high as 200 ft from the four 324-ft high towers (sketch, NU, Aug. '56, 74). A unique feature is its spherical core, made up of 21 fuel elements with enriched-U-Al plates joining to form many concentric cylinders, and made spherical by varying the length of the plates.

CONSTRUCTION TO START ON TWO POWER REACTORS

An immediate construction start was ordered on both the Carolinas-Virginia 17-Mwe pressurized heavy-water reactor at Parr, S. C., which was awarded its construction permit last month; and the 30–40-Mwe High Temperature Gas-cooled Reactor at Peach Bottom, Pa. The latter obtained approval of its site from the Advisory Committee on Reactor Safeguards; the reactor design already has AEC approval, so issuance of the construction permit is now considered a relative formality. ACRS found the site providing "a generally acceptable degree of isolation when considered in relation to the proposed high-integrity containment." Earlier the city of Baltimore and other communities had questioned the project's possible effects on their water supplies. ACRS also last month reported favorably on the application for an operation license for the materials testing reactor under construction at Plum Brook, Ohio, for the National Aeronautics and Space Administration.

GM WORKING ON PROCESS STEAM REACTOR

A General Motors missiles unit in Milwaukee is interested in building a process steam reactor for use at an undisclosed GM plant, and has informally sounded out AEC about it, but is worried about site safety.

WORLD NEWS

France to Build EL-4 in Brittany

A Breton site has been chosen for France's next big power reactor, the 100-Mwe EL-4, first to depart from France's graphite-moderated power units. The heavy-water-moderated reactor (NU, Feb. '60, 20) will be built in the Monts d'Arrée, a desolate mountain region 30 mi east of Brest. EL-4 is to be started late this year or early next, and will be on the line four years later.

SELNI Finds New Site, on Po River

After opposition to the SELNI utility group's Riviera site at Vallegrande culminated in the mayor's issuance of a decree prohibiting construction of any plant using radioactive materials (NU, April '60, 29), SELNI found an alternate site 83 mi NW for its 165-Mwe Westinghouse pressurized water reactor. This is on the Po river at Trino, 11 mi south of Vercelli and halfway between Turin and Milan in the heart of Italy's most important industrial area. The town has given SELNI a six months' option, and SELNI has already filed hazards reports with the national authorities; it hopes to get a green light and break ground very shortly. It is enthusiastic about the new site, which presents fewer technical problems, the ground being flat and firm with ample water available. Location of the SORIN research reactor at Saluggia only 12 mi east has accustomed the populace to the presence of nuclear plants in the vicinity. Transport and site preparation would be so much easier that SELNI could maintain its original schedule if authorization to proceed were to be issued without delay.

Austria Plans Reactor Criticality Sept. 30

The Austrian Atomic Energy Research Organization is planning a First-criticality ceremony Sept, 30 for its AMF pool-type research reactor at its new nuclear research center at Seibersdorf, 20 mi SE of Vienna. The $2-million 5-Mw reactor is expansible to 12-Mw, combines in one unit the second and third reactors planned in Austria's four-reactor path to nuclear power: a training reactor (the Ministry of Education is building a Triga in Vienna), a research reactor, a materials testing reactor, and finally a prototype power reactor. Austria still has 15–20 years of potential power expansion using hydro and fossil fuels before atomic energy becomes essential, but wants to get the necessary background at once to be able to start using nuclear power at any time. Having been prohibited from doing any nuclear research for ten years while the Allied occupation lasted, Austria had a lot of catching up to do—but by the same token was able to avoid repeating others' mistakes. The $6-million research center at Seibersdorf will keep 200 busy by year's end, 80 of them scientists and engineers; it plans to concentrate on "islands of research" not previously covered by others, and supplementing Austrian experience gathered through her participation in the Halden and Dragon projects of the European Nuclear Energy Agency.

AUSTRIAN NUCLEAR RESEARCH CENTER at Seibersdorf: building in foreground houses biology; parallel behind it are chemistry and metallurgy, and across road at left, health physics; at right angles behind reactor building are physics and electronics. Top left are administration, workshops and powerhouse. Top right (arrow) is IAEA's nuclear research lab.

India Moving to Four-Reactor Program

The somewhat-kaleidoscopic Indian nuclear power picture is beginning to become firm as a four-reactor program in the 1961–66 (third Five-Year Plan) period. Projected now are one large station of two natural-U reactors, 150-Mwe each, probably on the Arabian Sea coast between Bombay and the textile city of Ahmedabad; and two small reactor plants using enriched U, possibly in the Rajasthan desert region of northwest India, far from coal. Bombay was Mecca last month for Western reactor merchants, as top French and British reactor sales engineers followed Vasily Emelyanov to town (a U. S. group was already there [NU, April '60, 26] and another was reportedly expected). As might be expected, the British and French are after the big natural-U plants, the U. S. after the enriched-U units.

IAEA Working on Nuclear Power Costing

A ten-man panel of experts has been convened by the International Atomic Energy Agency to develop nuclear power costing methods. Its two specific assignments are: 1. to help IAEA draft documents on nuclear power costing to provide guidance for less-developed countries wishing to assess the possibilities for economic use of nuclear power; and 2. to guide IAEA's Secretariat on data to be submitted in a report on the present status of nuclear power costs to the 4th General Conference of IAEA this September.

Modifications for Dounreay Core

The first series of experiments having been completed, Britain's fast breeder at Dounreay will be shut down for three months while the core is modified so that a wider variety of fuel types can be tested.

Spain Moves to Build First Power Reactor

The Cabinet in Madrid took a concrete step toward building the long-hoped-for 30-Mwe dual-purpose (power and testing) reactor. It authorized Atomics International, whose organic-moderated design was selected as best of nine last year (NU, May '59, 34; Aug., 23) to work with the Junta de Energia Nuclear in preparing detailed plans and cost estimates for the plant for the Ministry of Industry. Thence they go back to the Cabinet for final approval. Financing is still a problem, but a high government official says it will be met by private enterprise and the government jointly.

General Atomic in German Licensing Deal

Gutehoffnungshütte Sterkrade A.G. of Oberhausen, West Germany, has obtained sole manufacturing and sales rights in Germany not only for General Atomic's Triga research reactor but also for its High Temperature Gas Cooled power reactor type. One of Germany's leading mechanical engineering firms, GHHS has been in the reactor-equipment field through its fabrication of a reactor vessel for the Karlsruhe research reactor FR-2 and the heat exchanger for the 15-Mwe AEC reactor in Kahl.

NEWS IN BRIEF

Sales Subsidiary Consolidated into Baird-Atomic

Baird-Atomic has consolidated its nuclear-equipment sales subsidiary, Atomic Associates, Inc., into the parent firm—a move it feels will streamline the B-A sales organization and strengthen the B-A corporate identity. Atomic Associates was acquired last year (NU, June '59, 31). The consolidation is also expected to cut down slightly on overhead. Atomic Accessories, another acquisition last year, will continue as a subsidiary with headquarters at Valley Stream, L. I.

Atomic Associates had been a sales representative for B-A, New England Nuclear Corp., and others. Its staff has become a part of the B-A sales force, under Richard Wood, at Cambridge, Mass., headquarters; the B-A sales staff will continue to represent all manufacturers previously represented by A-A except one (Pacific Electro-Nuclear Corp.).

U. S. Chamber Forms Task Force on Govt. Competition

The U. S. Chamber of Commerce has completed formation of a "Task Force on Increasing the Role of Private Industry in the Government's Atomic Energy Program," accepting the invitation of AEC Chairman John McCone to create such a group to work with AEC. Chairman is Philip N. Powers of Purdue Univ. Other members: Harllee Branch, Jr., president, Southern Co.; Harvey K. Murer, research director, General Foods; V. L. Parsegian of Rensselaer Polytechnic Institute; Arthur V. Peterson, president of his own firm; James M. Phelan, president Nuclear-Chicago Corp.; and George W. Wunder, National Lead Co.

The task force is a permanent committee of the Chamber. Some of its functions: to work up a statement setting forth principles for reducing AEC competition with industry; work with AEC "to reduce such competition"; review AEC's national lab report; review AEC's staff report on specific areas of competition cited by the Chamber (NU, Jan. '60, 22); and "emphasize the need for a clear, written, AEC policy statement in this area backed by instructions for implementation to all government installations."

The National Assn. of Manufacturers is also considering a task-force-type group in this area, although some opposition to this approach has cropped up.

AEC Launches New Educational-Recruiting Program

AEC, saying it is having trouble getting good nuclear scientists and engineers, has launched an 18-month training program for prospective employees of seven Operations Offices. The program includes nine months of graduate-level education at Oak Ridge or Argonne National Laboratories. About 30 people a year will be trained (also nine months in the Operations Offices) to handle technical assignments in the administration of reactor programs.

Interestingly, the program comes as the Commission is internally debating whether it should continue its equipment-grants to colleges and universities to increase the supply of manpower in the nuclear field (NU, March '60, 28). AEC General Manager Alvin Luedecke has approved the program as proposed by the staff, with some modifications, and it is now before the Commission itself.

AEC Drops "Horserace" on New Concept Reactors

Frank Pittman, AEC Reactor Development chief, has decided to drop the "horserace" program for reviewing new-reactor ideas (NU, Apr. '60, 30). Four proposals received under the last round of bidding are being reviewed under the new system—that is, the appropriate branch of the division will be assigned review of any new-concept proposal. And, instead of having semi-annual deadlines of Aug. 31 and Feb. 28, the division will accept proposals at any time.

U. S.-Soviet Exchange: Emelyanov Writes to McCone

Russian nuclear chief Vasily Emelyanov replied in March to a proposed AEC list of exchanges (men and data) on peaceful atomic energy (NU, Dec. '59, 24). However, the lapse of time between the U. S. suggestions of AEC Chairman John McCone and Emelyanov's reply—several months—is expected to delay implementation of the exchange agreement. Because of the delay, several of the exchanges proposed by Chairman McCone are no longer valid and a new series of correspondence may be necessary. Moreover, Emelyanov again raised the question of joint construction of projects in the high-physics and controlled-fusion areas and the U. S. is not prepared to go this far at present.

Meanwhile, the U. S. entertained a Yugoslav delegation on atomic energy and the groundwork was laid for a possible bilateral agreement, with the International Atomic Energy Agency acting as middleman. Yugoslavia is seeking U. S. aid in the way of at least one research-reactor grant.

AEC Proposes Rules for Regulatory Control by States

Proposed criteria under which AEC would transfer regulation of certain radioactive materials to capable state governments was sent to all governors last month. AEC went out of its way to emphasize that the criteria were only suggestions at this time and that counter-proposals and discussion were welcome. However, it said that where the criteria as they stand are acceptable to state governments capable of assuming control over the activities involved (radioisotopes, uranium, thorium and special nuclear material of less than a critical mass), they might be used as a basis for negotiation of transfer agreements. Three states appear to be well ahead of the others in ability and eagerness to assume these controls—New York, California and Texas. Some highlights of the proposed criteria:

1. Objective of a state regulatory program should be to protect the populace against radiation hazards and "encourage the constructive uses of radiation."

2. The states should adopt safety standards and strive for inter-state uniformity (in this area, AEC is preparing a "model" state program of laws and rules for use by any state desiring it).

3. AEC, in any transfer agreement, will transfer any one or all of the three major categories (isotopes, source materials and special nuclear materials) but no part of any category.

Physicist D. J. Hughes of Brookhaven Dead at 45

One of the architects of the nuclear age, Donald J. Hughes, died of a heart attack April 12, aged 45. A neturon physicist of international stature, Hughes' greatest contribution was to develop measurement techniques for, and compile and correlate, neutron cross sections—basic to all reactor design and to most other applications of nuclear energy. He is perhaps best known as author of the "barn book," the definitive collation of neutron cross sections. He was head of the neutron physics group at Brookhaven at his death.

RADIATION NEWS

RDI Sells First 2 Machines, Expands Capacity

In a banner month for Radiation Dynamics, Inc., youngest manufacturer of radiation machines, the firm disclosed the award of its first two machine orders. It will deliver to Grumman Engineering Corp., a high-current, Dynamag ion source for acceleration of hydrogen, helium, dueterium and heavier ions such as oxygen. The second machine—RDI's standard Dynamitron rated at 1 Mev, 10 milliamps—will go to the Cambridge Air Force Research Center, Mass. RDI also said it was doubling its manufacturing floor space and building a second machine vault to house a 3-Mev irradiator.

Walter Reed Medical Center to Buy Two Irradiators

A U. S. Army group working on the combating of radiation injury last month invited bids on a cobalt-60 irradiator of several thousand curies. A spokesman for the group—at Walter Reed Medical Center, Washington, D. C.—said a second, tandem irradiator totalling 20,000 curies of cobalt-60 would be acquired shortly after the first. The smaller source is needed for irradiation of mice and guinea pigs; specifications call for irradiation of an area 2 ft sq, 4 in. high at 125 r/min, with a variation over the flat surface of 5% and from floor to ceiling of 12%. The tandem irradiator—10,000 curies in each source—will be used to irradiate dogs in a cubic-yard chamber, with 5% variation through the space. Estimated cost of the equipment: $250–300,000. Early installation is scheduled for both irradiators.

New Isotopes Div. of ANS Already the Largest

The new Isotopes and Radiation div. of the American Nuclear Society, established last fall, has reached more than 350 members—largest of all ANS divisions. The division will sponsor its first papers at an all-day session during the June 12–15 meeting of ANS in Chicago. An ANS nominating committee has proposed Paul Aebersold, director of AEC's Isotope Development Office, for division chairman.

Russians Announce Pilot Irradiation of Potatoes

The Soviet Union's Institute of Biochemistry, Moscow, said last month that it will irradiate 25,000 lb of potatoes this year at a pilot facility in Moscow. The potatoes will be moved through a cobalt-60 gamma field on three passes. Potato irradiation has been shelved in this country but the Institute's biochemical-immunity chief, a Prof. Rubin, said "the time has now arrived when the process has been declared safe and suitable for large-scale use." The cobalt source may also be used, eventually, for other vegetables and fruits, he said.

U. K. Orders Linac for Radiography of 6-in. Steel

A 4.3-Mev linear accelerator, for radiographic inspection of reactor pressure vessels at least 6-in. thick, has been ordered by the U. K. Atomic Energy Authority. U. K. officials said this was something of a breakthrough in the power-reactor field because conventional machine and nuclide radiation was inadequate for steel plate more than 4 in. thick. The machine was developed by Mullard Equipment Co. for advanced reactors; it will produce a high-definition radiograph of 6-in. steel in 100 sec using industrial film and 60 sec using faster film.

RAI to Supply Cobalt-60 Source to Brooklyn Poly

Brooklyn's Polytechnic Institute has given Radiation Applications, Inc., a design and construction contract for a 1,000-curie cobalt-60 irradiator for use in low temperature, solid-state research. The device will take a Dewar flask 3¼ in. dia in a cavity 12 in. high, with a flux of 100,000–200,000 r/hr over the flask.

Tracerlab Reports Profitable Quarter, Big Backlog

President S. S. Auchincloss of Tracerlab told the firm's stockholders last month that the first quarter of this year was a profitable one for the firm, after a long period of losses. In March, he said, "we shipped more products and made a larger net profit than we have in any month since I have been president of the company. . . . A yearly profit is a good probability." He gave no profit figures but reported that backlog had reached a record level of $4-million. Earlier, the firm had reported a sales level for the last five months of $15-million (annual rate); sales for all of 1959 were $10,743,819.

N. Y. Firm Fabricating Isotope Space Battery

The prototype of an isotope-powered nuclear battery for use in outer space is expected to be delivered to AEC by the end of this month. The battery, a one-third to two-thirds watt electrostatic converter, has been under development for almost a year by Radiation Research Corp., New York City, under a $100,000 contract with AEC's Aircraft Reactors Branch. It is being fabricated by Radiation Research and Oak Ridge National Laboratory personnel in an ORNL hot cell. Although the prototype will deliver no more than a watt, its developers have "a pretty good idea what a 100-watt battery would look like" and ultimate goal is a kilowatt or more. The prototype will use 2,000 curies of cerium-144, a beta emitter, to feed a converter capable of producing electricity at 250 kilovolts.

Sales Representatives Organize Association

Ben Z. Rubin, owner of his own sales agency for the manufacturers of radiation instrumentation, said last month that a group of sales representatives have organized a sales "rep" association. Rubin was elected president; George Landfear of his own firm in Nutley, N. J., was elected vice-president; and Charles Walsh, also of his own firm, was elected publicity director. Major aim of the group: "To increase the status and prestige of independent representatives in the nuclear business."

Bureau of Mines Has Big Irradiation Program

The U. S. Bureau of Mines last month signed a formal agreement with AEC for the free supply of 100,000 curies of cobalt-60 for its planned research irradiator (NU, Jan. '60, 27). Subject to working out funding problems on the irradiator itself, the Bureau expects to begin construction this year at one of its research centers. Some highlights of the proposed research program:

Metallurgy. Based on preliminary work, the Bureau feels it may be able to use radiation for directly converting unspecified ores to pure metals, possibly in conjunction with a gas.

Coal. Exploration of radiation for increasing free-radical activity in anthracite, rendering it better able to react with chemicals. Also work on producing high-value chemicals directly from coal and certain additives; and micronization of coal to give it better burning properties.

Petroleum. Research on oil-field use of radiation, rather than at the finery stage. Would radiation be feasible for the destruction of bacteria in water used to restore pressure to "depleted" wells? (Bacteria acts on iron and sulfates in the water to clog valves, etc.)

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These four instruments are the first in a line of transistorized building-block nuclear instruments from RCL. Each instrument features transistorized reliability; modular construction; built-in electronic gating circuits; and plug-in etched circuit boards. Individual modules may be interchanged or combined to provide many basic functions and combinations. In addition, etched circuit boards may be substituted within individual modules to produce extreme flexibility and versatility of application.

The modules and etched circuit boards pictured above can be combined to form an extremely sophisticated scaler or, if desired, more modest (and less costly) but highly useful ones. All scalers feature an in-line Nixie count display, in-line time register display and direct reading dials for continuously variable preset count functions.

MODULES ARE AVAILABLE INDIVIDUALLY OR IN COMBINATIONS

Linear Amplifier can withstand input pulses up to 100 times greater than those required for full output, with fast recovery and without double-pulsing. Full scale output is 25 volts. A stabilized gain of 1000 with a 100 ohm input attenuator provides input factors of 1, ½, ¼, ⅛, and ⅛. A potentiometer affords fine gain variation between these fixed factors.

Positive or Negative High Voltage Power Supply is continuously variable in a single range from 500 to 3000 volts. It is controlled by a three-turn Helipot which is accurate to ± 0.5 per cent with an adjustment precision of ± 2 volts. For a ± 10 per cent line voltage change, high voltage output varies less than 0.02 per cent, and a change from no-load to full-load produces less than 0.1 per cent variation. Output is read in kilovolts on the Helipot and also is indicated on a panel meter. The Power Supply may be used with scintillation, proportional and Geiger-Mueller detectors.

Scaler and Timer operate as a unit in this instrument. The Scaler is available with either one MC or 100 KC input. A reversible printed circuit board can accept amplifier output or direct GM input. Up to 99,999,999 counts can be displayed on a horizontal line of Nixies. The Scaler has five switch-selected modes of operation: Preset Count (Any count from 100 to 99,999,900 in steps of 100); Preset Time (Any time from 0.01 minute to 999.99 minutes); Manual; Count Only (Timer is inoperative.); and Test (line frequency).

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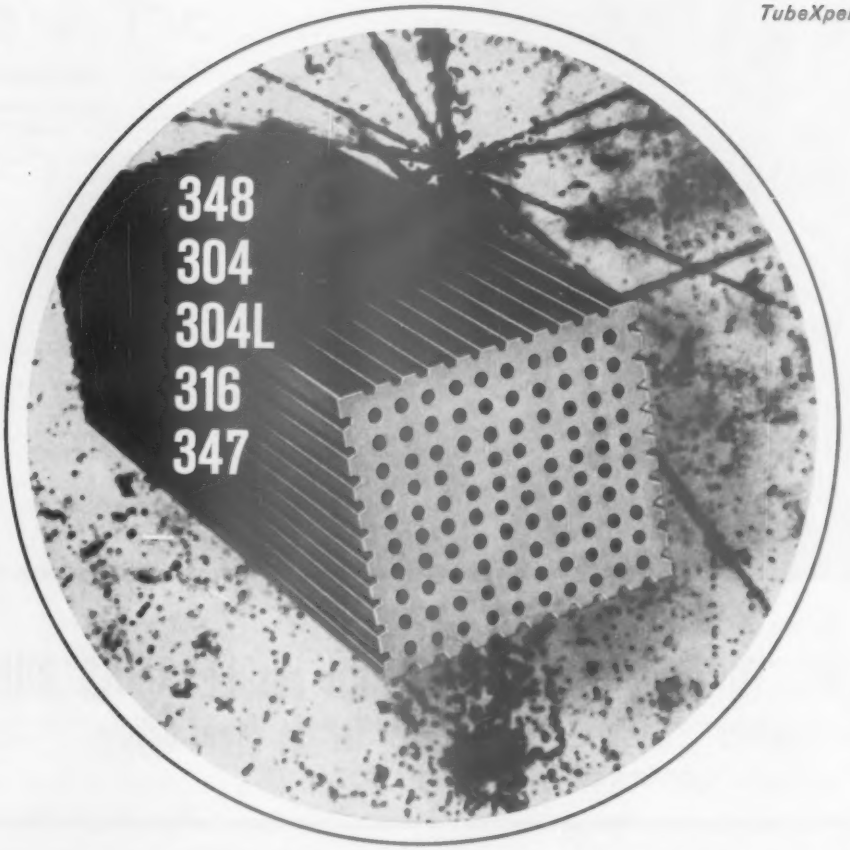

Superior now offers 5 different analyses of stainless tubing for fuel element cladding

Before selecting tubing for fuel element cladding in nuclear reactors, consider the stainless types now offered by Superior. Important characteristics are listed in the table, but there are other important advantages, too. Closer tolerances can be maintained than with such materials as zirconium or columbium and their alloys. Better surface finishes are available. And higher reliability in chemical composition, availability and fabrication into the basic mill forms needed for producing small-diameter tubing is possible.

Superior Specification STC-102 outlines the quality and technical requirements of Nuclear Quality Fuel Element Tubing in these austenitic stainless steels. Write for your copy today. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

TYPE	REMARKS
348	1. Good strength at elevated temperature 2. Low neutron absorption characteristics 3. Stabilized against injurious carbide precipitation 4. Most widely used analysis for this purpose
304	1. Most economical of all alloys listed 2. Strength at elevated temperature good, but not as strong as 316, 347 and 348 3. Good for all-around applications 4. Excellent ductility and fabricability
304L	1. Excellent welding characteristics 2. Best ductility, fabricability 3. Less expensive than 316, 347 and 348 4. Lowest strength at elevated temperature of alloys listed
316	1. Best strength at elevated temperature 2. Excellent corrosion resistance in reactor coolants 3. Good fabricability 4. Creep strength best of 300 Series
347	1. Good strength at elevated temperature 2. Neutron absorption characteristics generally higher than those of 348 3. Stabilized against injurious carbide precipitation 4. Less expensive than Type 348

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In tests recently made with a Van de Graaf generator, the E-1C, utilizing an improved proton recoil detector, conclusively demonstrated its adherence to the first collision tissue dose curve.

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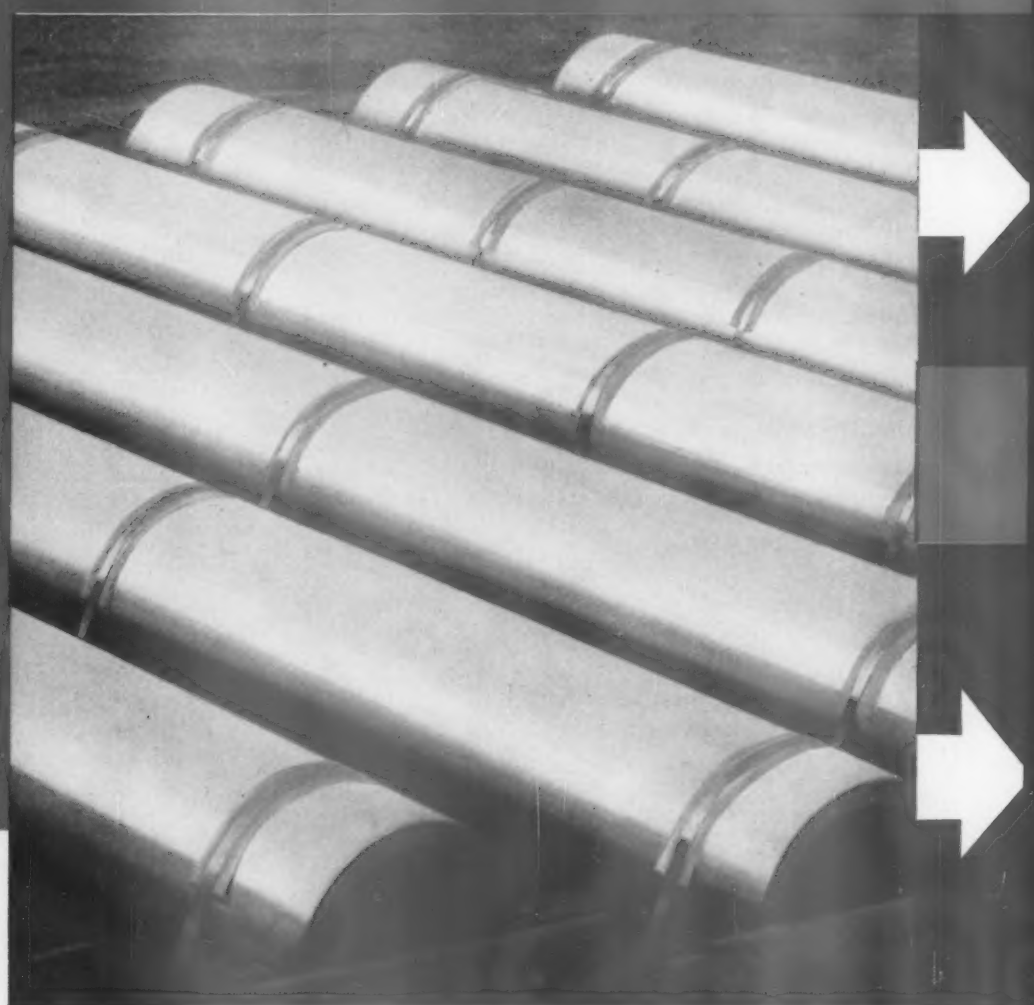


Centrifugal stainless steel castings readied for shipment by U.S. Pipe

The Government's new SPERT III nuclear plant at the National Reactor Station near Idaho Falls, Idaho, operating since December, 1958 to study nuclear reactor safety, uses U.S. Pipe's centrifugally cast stainless steel pipe for its coolant system.

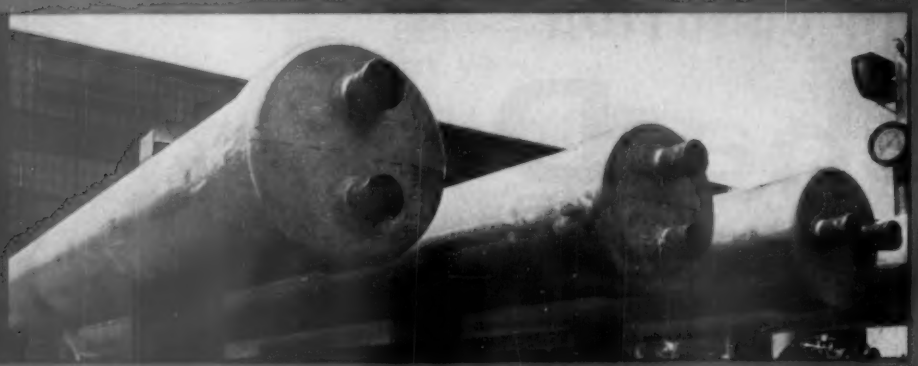
SPERT III is classified as a high pressure, high temperature, light water moderated and cooled reactor. Its versatility permits transient tests under various initial conditions of pressure, temperature, and coolant flow. For example, pressures ranging from atmospheric to 2,500 psi and water temperatures from 68° to 668° F.

Another new nuclear power plant, engineered and constructed by Stone & Webster for Yankee Atomic Electric Company, is using centrifugally cast stainless steel heat exchanger shells made by U.S. Pipe and fabricated by the Southwestern Engineering Company in Los Angeles, Calif.

Stainless steel, centrifugally cast, made to rigid specifications, may be the answer to your piping or heat exchanger problem. For more information, write or call:

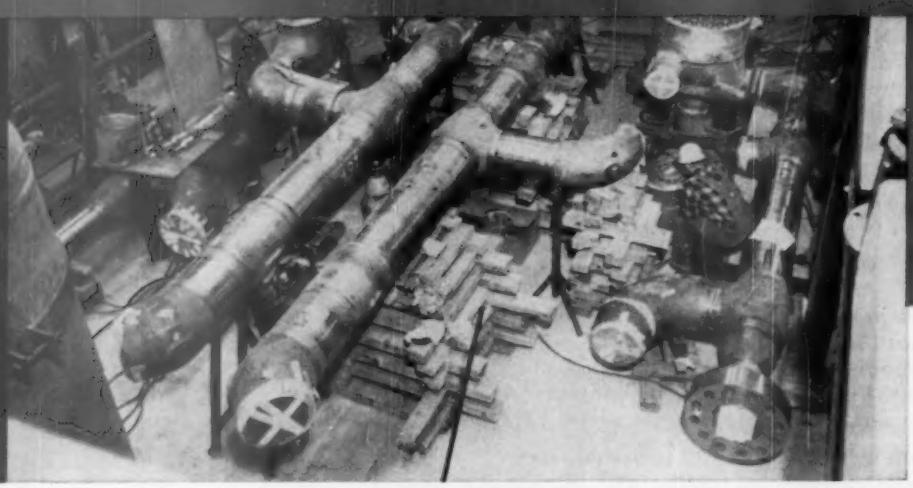
centrifugally cast stainless

REQUIREMENTS OF NUCLEAR AND COOLANT SYSTEMS



Shop-fabricated heat exchanger shells of centrifugally cast stainless steel ready for shipment to the Yankee Atomic Electric plant at Rowe, Mass.

Subassemblies of primary coolant piping of centrifugally cast stainless steel being installed in SPERT III.



ASA PRESSURE PIPING CODE STATUS

Approval has been granted under this code for the use of centrifugally cast austenitic pipe for nuclear piping by Nuclear Case N-9. This case appeared in the April, 1960 issue of MECHANICAL ENGINEERING. Reprints on request.

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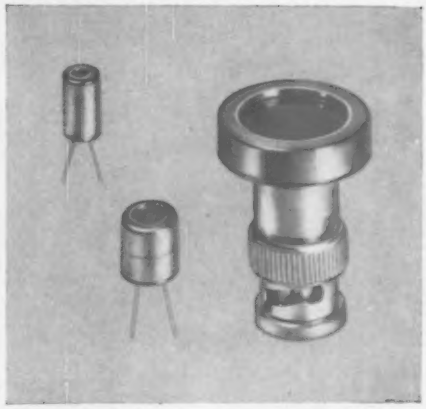


with optimum geometry, high resolution, large area detection

A product of the Research Laboratories of RCA Victor in Montreal, this silicon junction alpha detector marks a major advance in radiation detection. It is a small, rugged "solid state ionization chamber" capable of detecting individual alpha particles of energy 0.5 Mev or more.

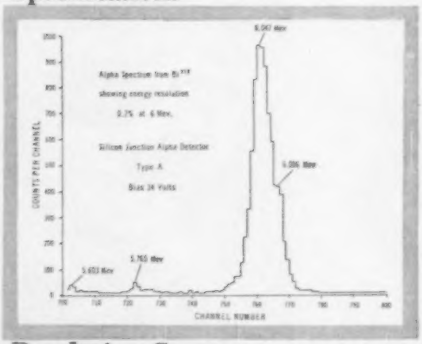
It can be used as a proportional counter over a range of approximately 1.5 to 10 Mev with excellent linearity and a resolution of better than 1% at 5 Mev. Also useful for protons, deuterons and heavy ions.

Fig. 1 shows provisional specifications for several types. Units with larger voltage, higher resolution, larger or smaller area, faster response time and so on can be made to special requirements. Existing units available in sample quantities.

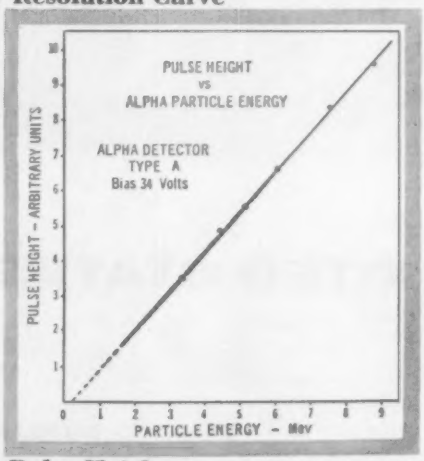
Inquiries are invited with regard to performance data and the development of specific applications. Write: Director of Research, Research Laboratories, RCA Victor Company, Ltd., Montreal 30, Canada.

TYPE	A	B	C	D	F
Detecting Area	5mm²	5mm²	20mm²	20mm²	2cm²
Maximum Operating Voltage	50v	10v	50v	10v	25v
Resolution for 5Mev α–Particles	<1%	–	<2%	–	–

1 Specifications



2 Resolution Curve



3 Pulse Height

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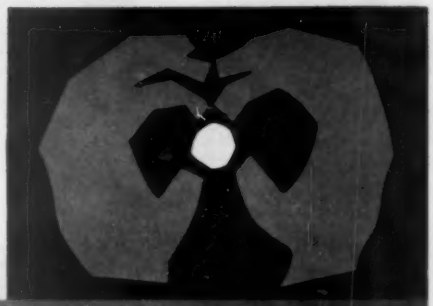

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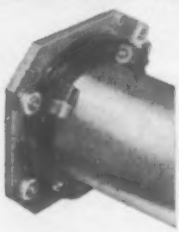
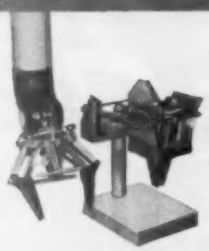
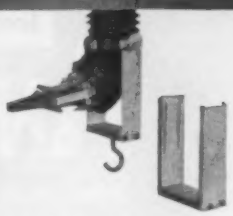


Improved *roller mount:* More rugged, more serviceable, less wear on through tube.

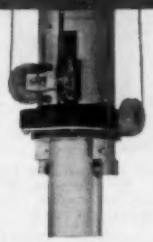


Improved *wrist joint, tong,* and *tong jig:* Greater protection of gears, more rugged, easier interchange.

Improved *handle:* More rugged, more satisfactory control of separation indexing and squeeze motion lock.



Improved *booting* and *load hook: Partial or* complete booting possible, load hook fits on booted or unbooted arm.



Improved *azimuth assembly:* Eliminates exposed rollers, provides greater "Z" motion or shorter collapsed length.

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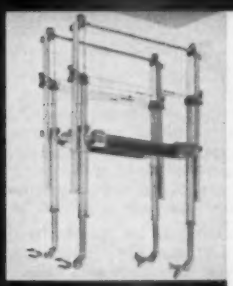

for over-wall installation

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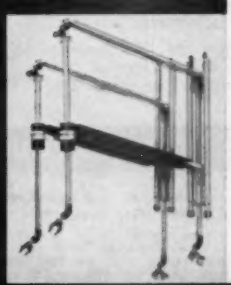

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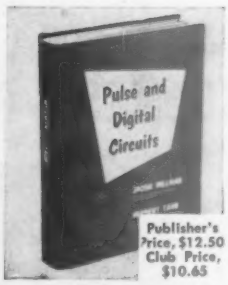

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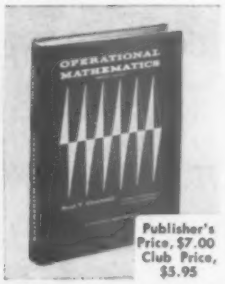

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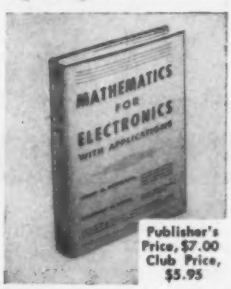

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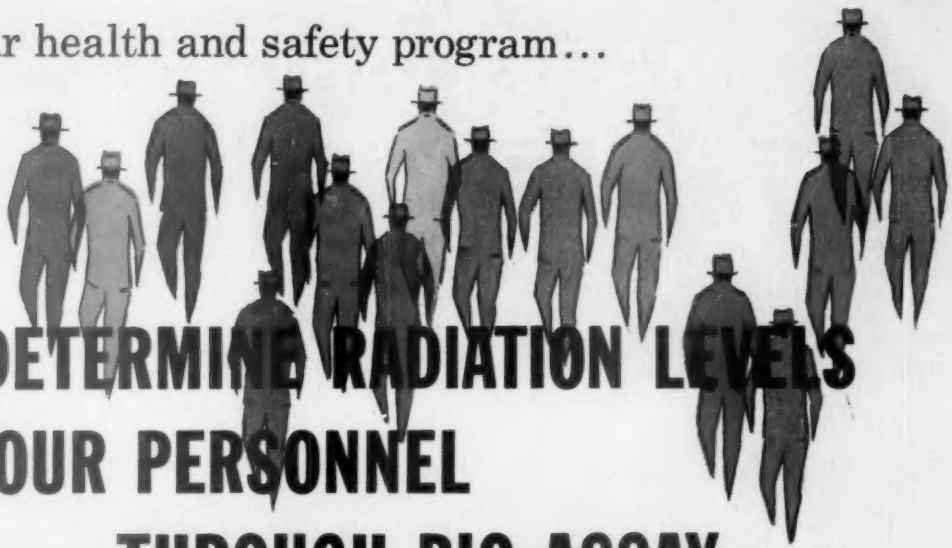

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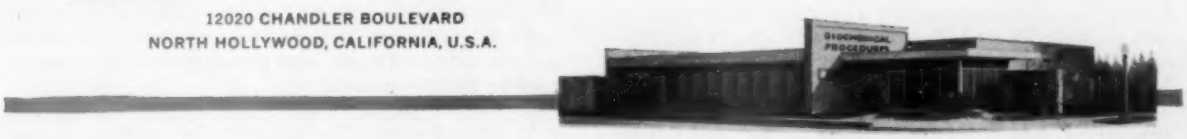

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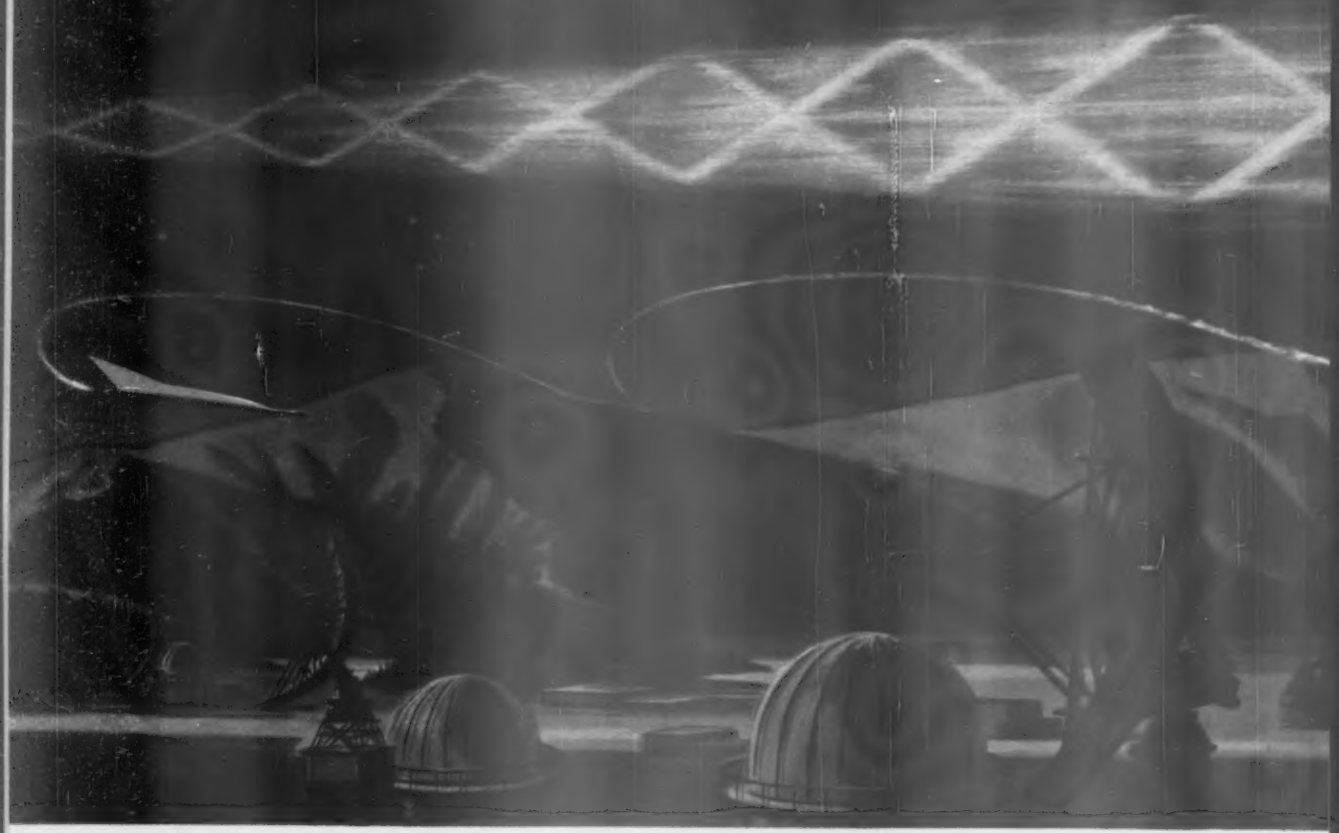

Broadened team effort with University of California's Lawrence Radiation Laboratory aims toward early feasibility demonstration of a nuclear ramjet reactor (Project PLUTO).

A supersonic, low-altitude missile capable of weaving, feinting and dodging unobserved by conventional radar while seeking out selected targets—this is to be the mission of the Air Force's proposed nuclear ramjet-powered vehicle of virtually infinite range.

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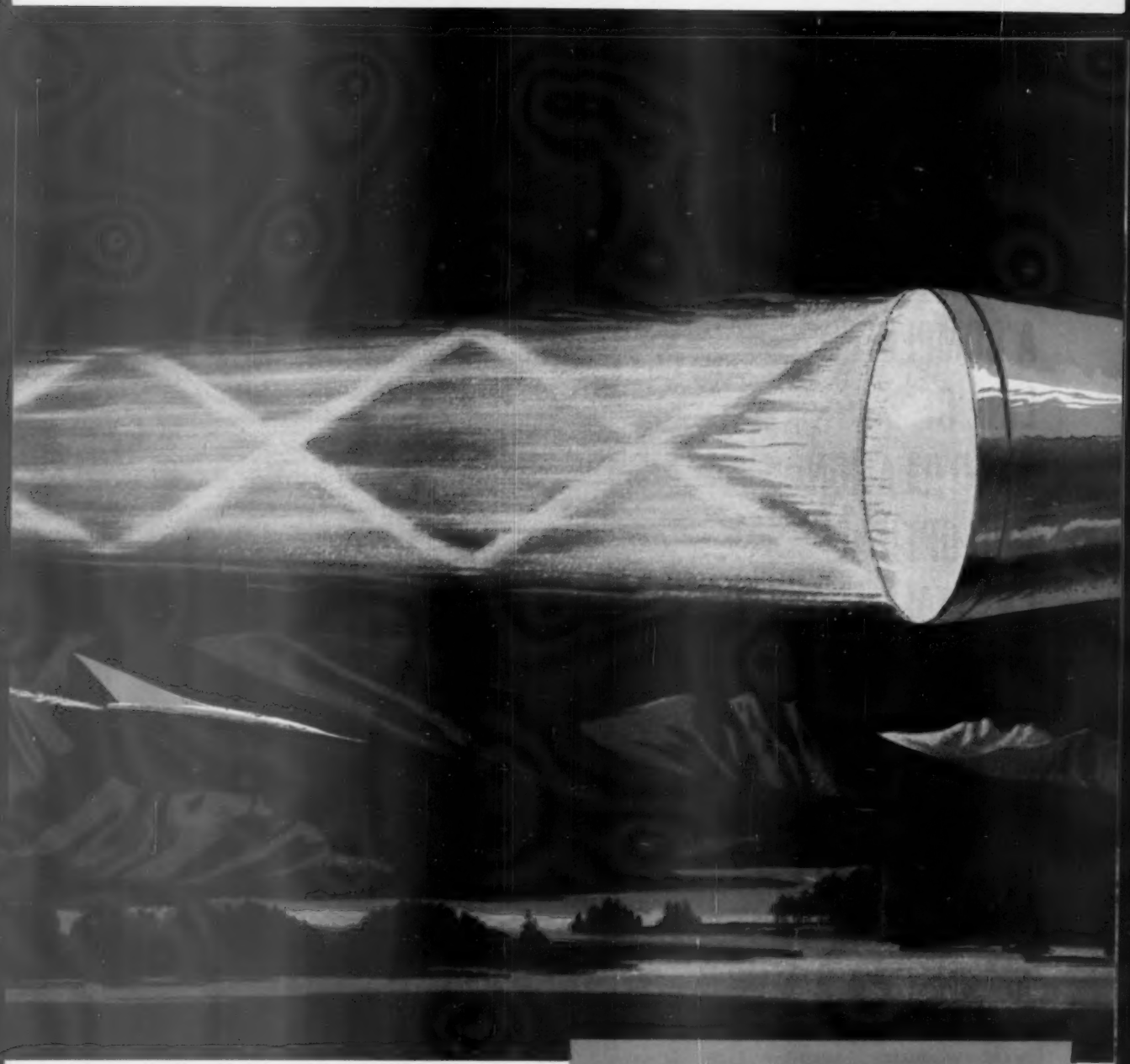
Marquardt's basic PLUTO effort concerns preliminary design of the nuclear ramjet and development of airborne reactor controls and other components for severe temperature and radiation environments. The multi-million dollar program supports a multi-phase corporate effort headed by the Nuclear Systems Division.

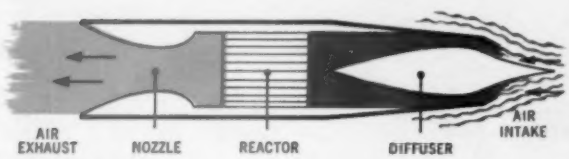
Other aspects of Marquardt's PLUTO effort include: support of LRL's feasibility tests on the non-flyable Tory IIA reactor; design and fabrication of significant portions of the reactor's control system, air ducts, flow instrumentation and remotely operated disconnects; fabrication and test of reactor core structural components; architect-engineering on the test air supply system; participation in a supporting program of environmental tests; and preliminary design of test facilities for full-scale power-plant development.

Highlights of the Corporation's other current nuclear programs include: exploration of both military and non-military applications for transportable reactors of advanced design, including their use for space power; development of the engine control system for the G-E nuclear turbojet; research studies of advanced space propulsion devices utilizing nuclear concepts; materials and processes work with molybdenum, other refractory metals and ceramics; and development of original nuclear instrumentation.

For a copy of Marquardt's new "Nuclear Systems" brochure, write to Mr. Aikman Armstrong, Chief Applications Engineer-Nuclear Systems, The Marquardt Corporation, Van Nuys, California.



THE NUCLEAR RAMJET



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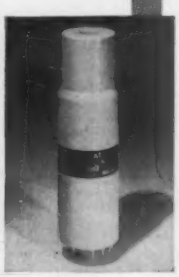

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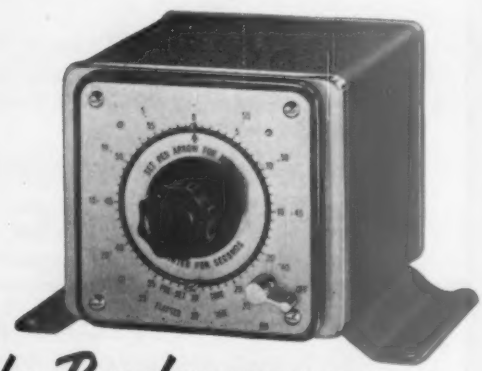

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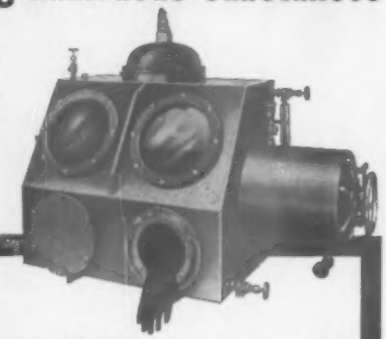

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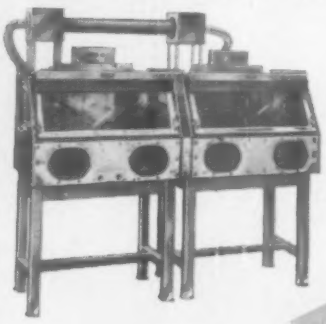

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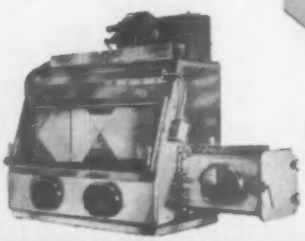

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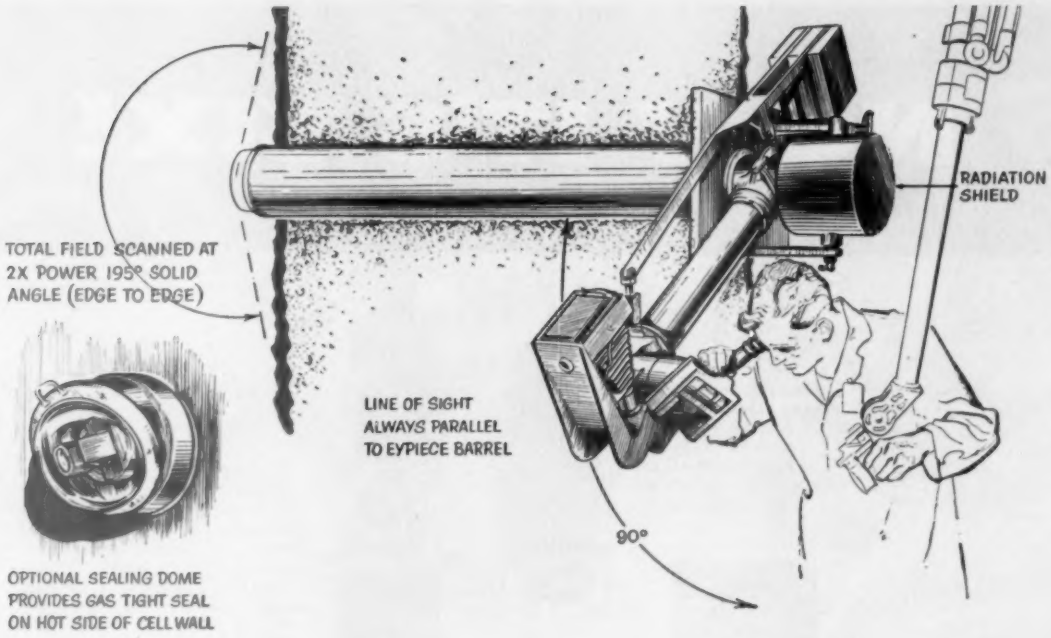

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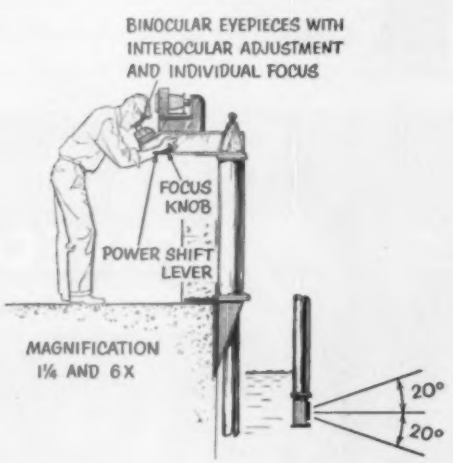

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NUCLEAR REMOTE VIEWING EQUIPMENT • SUBMARINE PERISCOPES • OPTICS • BORESCOPES • MOTION PICTURE AND TELEVISION LENSES • PRECISION OPTICAL INSPECTION AND ALIGNMENT DEVICES • ELECTRONIC CONTROLS AND COMPONENTS • NAVIGATIONAL AIDS

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COSTELLO & COMPANY, LOS ANGELES, CALIFORNIA.

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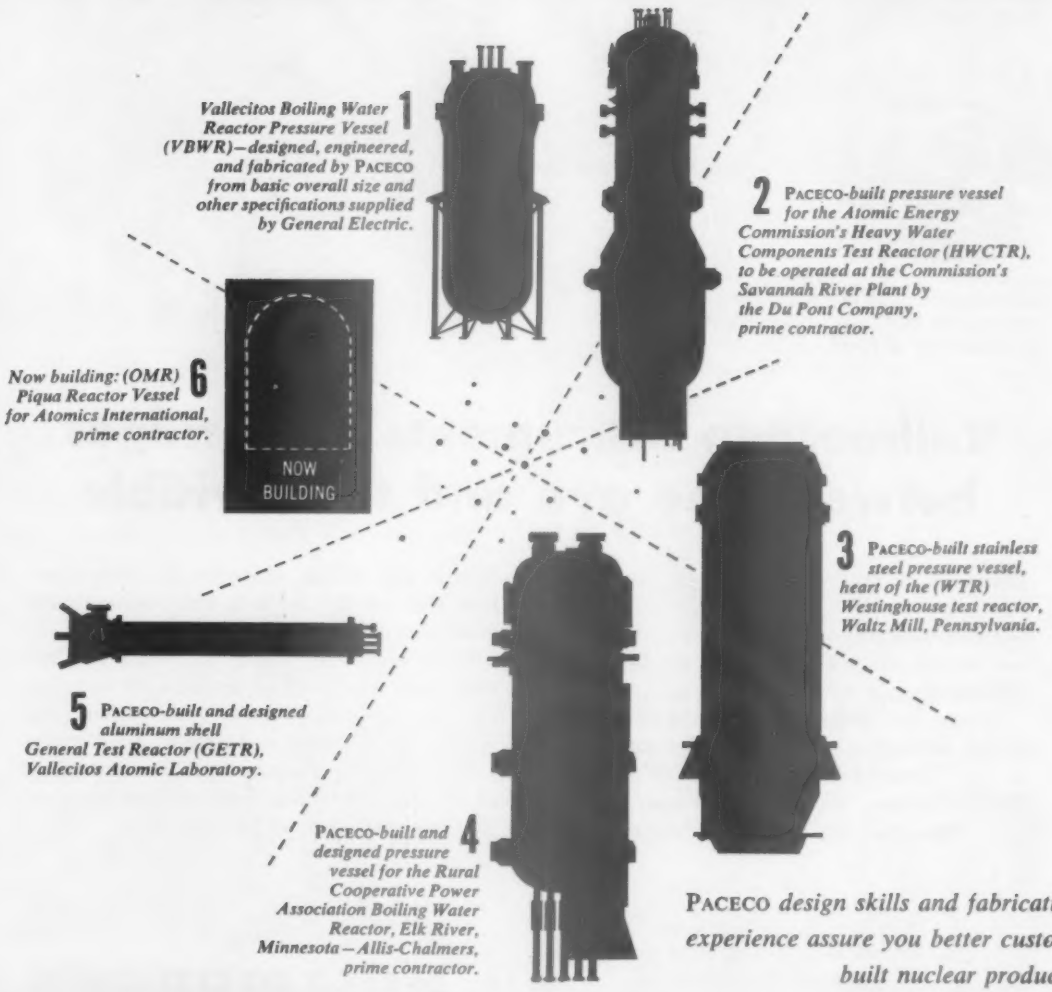

1 *Vallecitos Boiling Water Reactor Pressure Vessel (VBWR)—designed, engineered, and fabricated by* PACECO *from basic overall size and other specifications supplied by General Electric.*

2 PACECO*-built pressure vessel for the Atomic Energy Commission's Heavy Water Components Test Reactor (HWCTR), to be operated at the Commission's Savannah River Plant by the Du Pont Company, prime contractor.*

3 PACECO*-built stainless steel pressure vessel, heart of the (WTR) Westinghouse test reactor, Waltz Mill, Pennsylvania.*

4 PACECO*-built and designed pressure vessel for the Rural Cooperative Power Association Boiling Water Reactor, Elk River, Minnesota—Allis-Chalmers, prime contractor.*

5 PACECO*-built and designed aluminum shell General Test Reactor (GETR), Vallecitos Atomic Laboratory.*

6 *Now building: (OMR) Piqua Reactor Vessel for Atomics International, prime contractor.*

PACECO *design skills and fabricating experience assure you better custom-built nuclear products.*

PACECO has designed and built equipment for almost every project of the AEC during the past 10 years as well as privately financed plants. In addition to pressure vessels, PACECO products include linear accelerators, leaded containers, towers, cranes, and many other items for the nuclear industry.

Take advantage of PACECO's experience and skills in the nuclear field. Contact your nearest representative.

FREE ON REQUEST: BROCHURE 5-N,
"CUSTOM BUILT EQUIPMENT FOR NUCLEAR PROJECTS"

PACIFIC COAST ENGINEERING CO.

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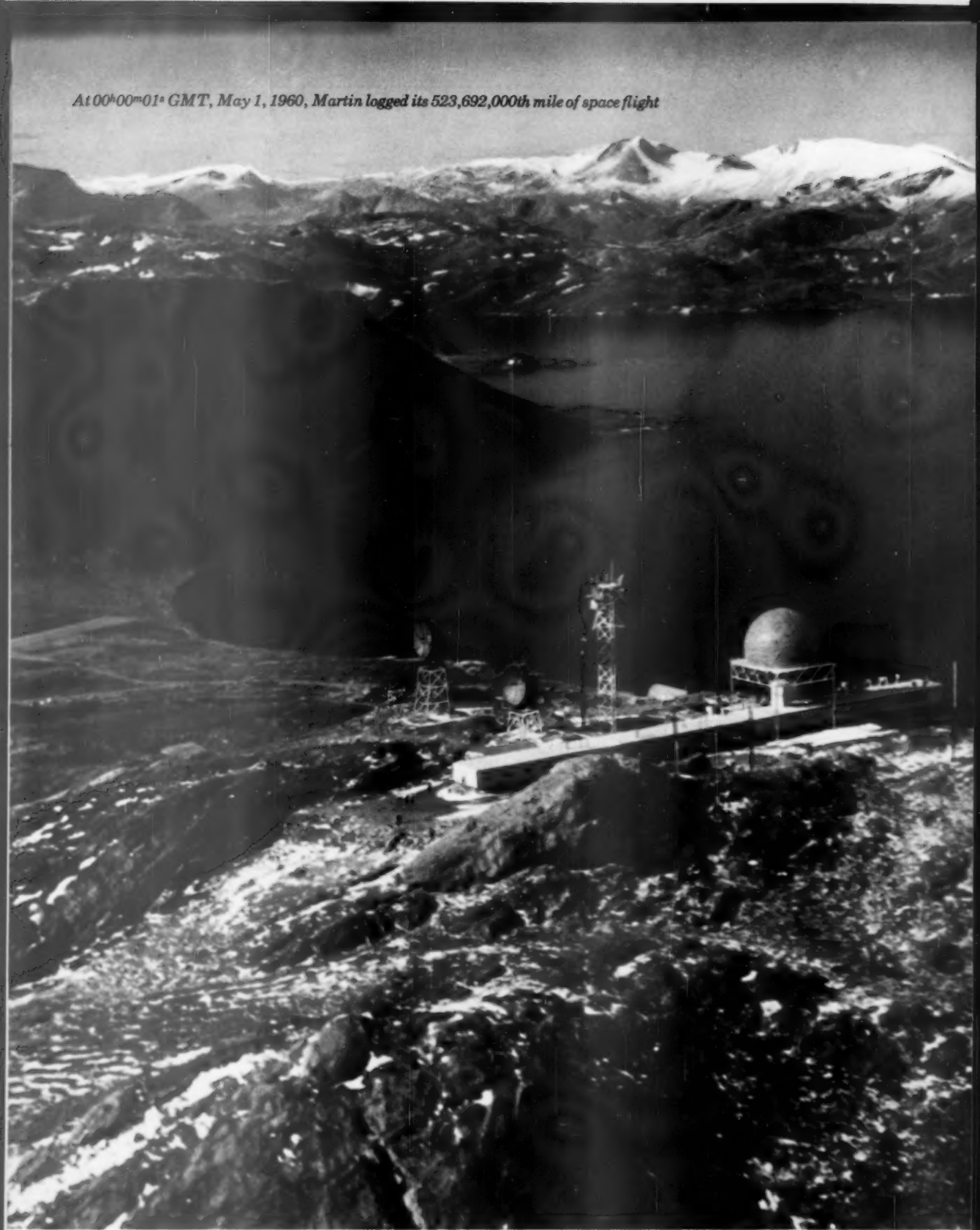

To keep the lonely vigil . . . Martin PM-1 air-portable nuclear reactor, to supply electricity and heat at remote Air Force stations, is now being developed and produced for the AEC.

MARTIN

"Higher Education . . . Our Greatest Tool"

OSCAR G. MAYER

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"During the last twenty years we have had dramatic evidence of what massive research can accomplish. Every thinking American today is acutely aware that our future welfare depends upon this vital activity.

"But sound higher education is the prerequisite of good research; it is vitally important that our higher education be constantly improved, beginning with our secondary schools. Higher education is the only means with which we can mine our most valuable natural resource: the creativity of the human mind in all fields, social and cultural as well as scientific.

"By supporting the college of your choice in its efforts to provide the best possible faculty and physical facilities, you are investing in the one tool with which to shape favorably the future of America."

If you want more information on the problems faced by higher education, write to: Council for Financial Aid to Education, Inc., 6 E. 45th Street, New York 17, N. Y.

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is now being developed and produced for the ALC.

New "plasma thermocouple" for DIRECT CONVERSION

Experimental "plasma thermocouple," developed by Los Alamos Scientific Laboratory, converts heat from nuclear fission directly into electric power.

relies on ruggedness of ALITE® INSULATORS

Recent successful demonstration of the Los Alamos "plasma thermocouple," which turns nuclear reactor heat directly into electric current, marks a major step toward the goal of utilizing nuclear energy for outer-space propulsion. The Alite insulator assembly above helps make it possible.

Alite—the special high-alumina ceramic developed by U. S. Stoneware—has many useful nuclear properties. In this application, an essential requirement was met by Alite's ability to maintain high electrical insulating strength in the presence of radioactive energy and elevated temperatures. Also extremely important here: Alite's vacuum-tightness, its resistance to cesium vapor, and the fact that Alite can be metalized, brazed to metal parts and readily welded into final assemblies.

Strong, hard, corrosion and abrasion resistant Alite may be the material you need to meet difficult nuclear design specifications. Write us about your requirements. Our ceramics specialists will provide all possible assistance.

For complete technical data on Alite and Alite Ceramic-to-Metal Seals, write for Bulletins A-7R and A-40.

ALITE DIVISION

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BOX 119 ORRVILLE, OHIO

486-F

KANIGEN®

The proved nickel alloy chemical plating—available only from General American and its licensees

KANIGEN is a chemically and metallurgically unique process for applying a hard, corrosion and abrasion resistant surface to most metals. KANIGEN is being used successfully for coating almost everything of any size—from the inside of a tank car to a tiny surgical needle—providing extreme uniformity of coating thickness even on complex shapes. Rack, jig or barrel plating may be used with KANIGEN.

Since KANIGEN is a nickel alloy, it has many qualities which make it desirable for nuclear applications. Valves, pumps, pressure vessels, tube bundles and headers are typical of the pieces that have been successfully plated with KANIGEN.

KANIGEN is available from General American at East Chicago, Indiana; Sharon, Pennsylvania, and Compton, California, and from licensees in many cities. For further information, call or write.

KANIGEN is a trademark which identifies chemical nickel coating by General American Transportation Corporation and its licensees, the product resulting therefrom and compositions produced by them for use in chemical nickel coating.

PHYSICAL PROPERTIES

Specific gravity 7.9
Melting point . . . . . 1635 °F
Electrical resistivity
approximately 60 micro-ohms/cm/cm²
Coefficient of expansion
13 x 10^{-6} cm/cm per °C or
7.22 x 10^{-6} in/in per °F
Thermal conductivity
approximately 0.0105 to
0.0135 cal/cm sec °C (calculated)
Hardness
as plated—49 Rockwell C
heat treatable to 70 Rockwell C

World's largest production facilities for chemical nickel alloy plating on

Iron
Copper
Aluminum
Titanium
Beryllium
and their alloys

Pilot plant facilities are available for nickel alloy chemical plating on magnesium, uranium and non-metallics including thermosetting plastics, glass, ceramics.

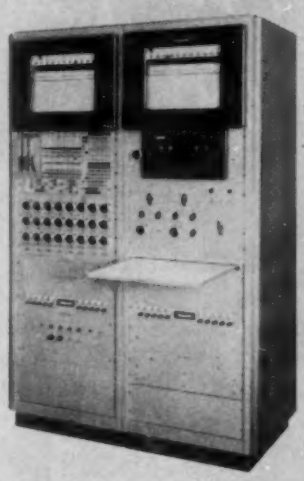
Kanigen Division

GENERAL AMERICAN TRANSPORTATION CORPORATION

135 South LaSalle Street • Chicago 3, Illinois

Honeywell Nuclear Reactor Simulator
. . . unmatched for realistic training!

NUCLEAR REACTOR SIMULATOR responds like a low-power, research type reactor, and covers a range of 0-150 percent of reactor design power. It includes simulation of poison effects and negative temperature coefficients. Interchangeable plug-in units make possible the realistic reproduction of reactor operation with U-235, U-233, and plutonium fuels.



THERMAL PLANT SIMULATOR can be teamed with the Reactor Simulator for realistic nuclear power plant training. It has plug-in connectors for typical power plant programs . . . patchboard panel for non-standard programs.

Nothing short of experience with an actual reactor provides the practical training students get with the realistic Honeywell Nuclear Reactor Simulator. This Simulator accurately reproduces important reactor functions electronically instead of by nuclear reactions. Its full-size amplifiers, recorders, and control instruments are identical with those used in many existing reactors.

This highly flexible Simulator is the safe, simple, and economical way to teach reactor characteristics, operating procedures, instrumentation, and interpretation of chart records. Use it with the Honeywell Thermal Plant Simulator for valuable training in nuclear power plant engineering.

Your nearby Honeywell field engineer can give you complete details. Call him today . . . he's as near as your phone.

MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.

75th YEAR PIONEERING THE FUTURE

Honeywell

First in Control

SINCE 1885

One of a series of discussions on topics of particular interest to those employing radioisotopes and tracer techniques.

LIQUID SCINTILLATION COUNTERS

If you plan to buy a Liquid Scintillation Counting System, the *only* important criteria are:

1. The counting efficiency and background;
2. The number of samples to be counted;
3. The cost of the system and,
4. The reputation and experience of the manufacturer.

As you know, the first commercial Liquid Scintillation Counting System was produced at Tracerlab back in 1954, and we believe that our newest system, the LSC-10, is the most economical and practical ever designed.

The Tracerlab system consists of a console for the scaler and associated circuitry, and a freezer containing the sample changer and detectors. The unique detection system is a coincidence type with two photomultiplier tubes mounted at right angles to each other. The freezer, an 11 cubic foot unit, is only 38" wide, and has a capacity of forty-20 ml. samples with an in-freezer storage rack for 40 more. Yet it is compact enough to be practical even for crowded laboratories. Phototubes are fully protected against accidental light exposure by means of a freezer mounted interlock.

Here's another point to consider: In the LSC-10 system, you don't have to open the freezer to transfer samples. External controls are provided — samples remain dark adapted — you get uniform counting conditions. Incidentally, the LSC-10 can be readily converted, *in your laboratory* to fully automatic operation (by means of standard accessories) if and when your volume of work requires it.

Experts agree that both low temperature and coincidence circuitry are an absolute necessity for low background and stable operation when counting tritium or low concentrations of carbon-14. Tritium compounds are among the most difficult to assay, particularly when in aqueous solutions. A look at the final test records made on five typical units, in series shows the following efficiencies and backgrounds for counting aqueous tritium.

And, remember, these units can perform even better when installed in your laboratory with settings optimized for your counting requirements.

Unit	Efficiency and Background
A	9.0% at 95 cpm
B	6.2% at 70 cpm
C	7.6% at 73 cpm
D	6.2% at 83 cpm
E	5.3% at 64 cpm

Naturally, much higher efficiencies are obtained when counting non-aqueous tritium or carbon-14 compounds. Greater than 75% efficiency can be expected when counting C-14 samples and greater than 25% efficiency when counting tritium compounds in hydrocarbon solution.

Further facts about the LSC-10.

THE COST?.....The lowest for any fine system.

DELIVERY?..Currently less than 30 days.

INSTALLATION?.....Usually completed in a matter of hours.

SERVICE?.....It's world-wide, with more than 100 qualified representatives.

INTERESTED?.....*Write for a quotation and full details.*

Tracerlab *first in radiation measurement*

TRACERLAB, INC., 1610 Trapelo Rd., Waltham 59, Massachusetts • 2030 Wright Ave., Richmond, California • 2419 South Blvd., Houston, Texas.

experience (eks pē'ri ens) n. Skill or wisdom gained by actually doing things. Knowledge gained by trial and practice. v.t. To undergo; to know or learn through one's own actions.

Doing is experience. Vitro has already designed **two billion dollars** worth of nuclear facilities ..whose usefulness has been expanded by the early application of new engineering techniques. This experience assures you an on-time facility — and profitable design which remains competitive for years to come. Find out today how this background can be put to work for you.

engineering the future

Vitro ENGINEERING COMPANY

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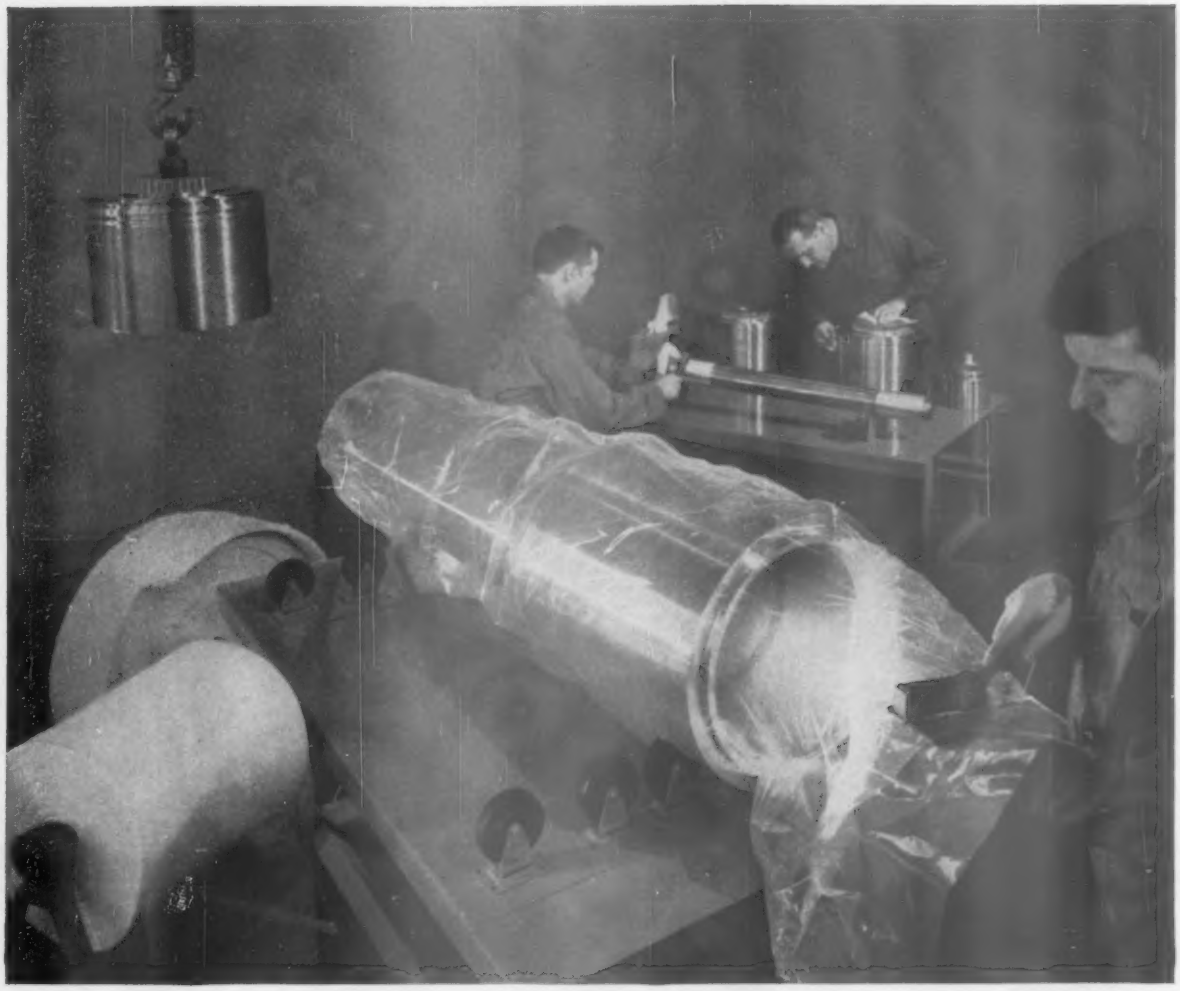


Reactor vessel core access housing, foreground, is almost surgically clean when sealed in polyethylene sleeve. Plug rides on overhead stainless steel hook. Under SPS Nuclear Division procedure, the slightest puncture in plastic before crating demands complete recleaning, repackaging and inspection.

Operation hound's tooth

Where reactor components are involved, ordinary cleaning and packaging procedures are out. In their place, SPS applies methods so painstaking that the typical component is shipped out in almost surgically clean condition. For example, dips are made in acetone, or pure alcohol only, to prevent residual chlorides—chemically undesirable in an atomic vessel. The flushing bath is distilled water—never tap water. And for hoisting and handling, galvanized hooks or slings are prohibited, zinc being another possible contaminant. Wiping, of course, is done with absolutely lintfree materials.

Once dry, a part is not touched again by hand until sealed in a polyethylene sleeve (no oil paper—it may contain sulfur traces). And should the plastic sleeve accidentally be punctured prior to crating the part, the entire cleaning, packaging and inspection operation is repeated from scratch.

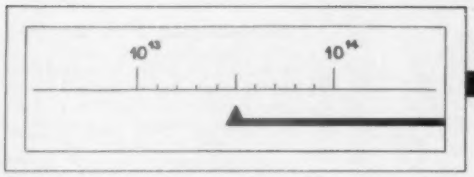
Such meticulous methods are the essence of SPS reliability—a policy of doing the job even more thoroughly than demanded in order to assure 100% predictable performance. And in nuclear devices—portions of which may be permanently inaccessible—nothing less is really acceptable. If you have requirements in this field (for reactor components or for conventional power-producing machinery), contact SPS—manufacturer of precision threaded fasteners and allied products in many metals, including titanium. Request Bulletin 2499.

NUCLEAR COMPONENTS Division

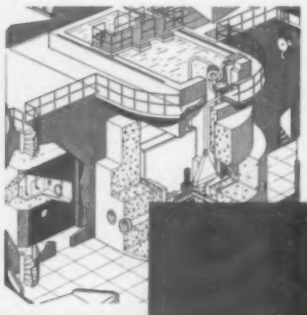
JENKINTOWN 45, PENNSYLVANIA

SPS

where reliability replaces probability



The highest flux...



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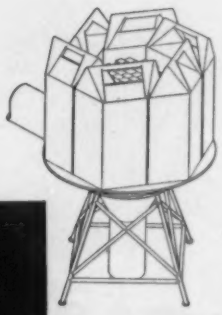
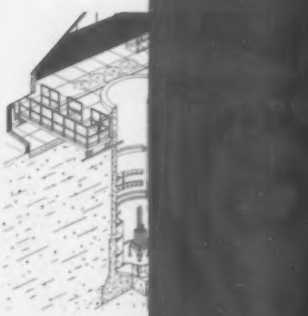


CHANTAL



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RESEARCH
REACTORS
BUILT BY

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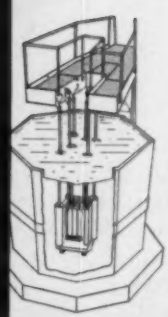
MINERVE



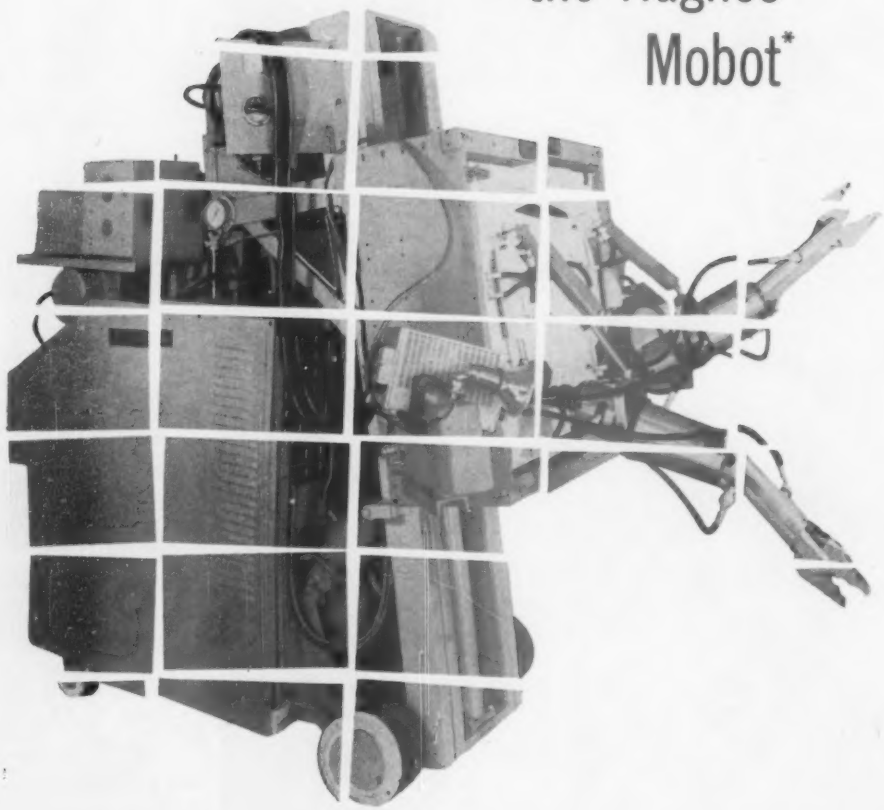
POCKET REACTOR

INDATOM

48, rue la Boétie, PARIS VIII^e^ (France)

...for the lowest price

now in modular form— the Hughes Mobot*



Manipulating Arms, Power Unit, Control Console, Television System, Vehicle, Command System—these are the building blocks which make up the new Hughes Mark 1-B Modular MOBOT.

These modules provide the flexibility needed to meet almost any remote controlled handling problem—be it fixed, semi-mobile, or fully mobile. For example, the arm (or arms) can be installed on a wall, pole or boom. To add mobility, the arm can be installed on a vehicle (with television if required). Any of these systems can be expanded or the location of modules can be changed as needed.

The new Modular Mobot is the latest product of the Hughes Nuclear Laboratories—specialists in RADIATION—solid state detectors and detection systems, research LINACS, facilities, radiation effects analyses, and remote handling equipment.

For complete engineering bulletins on any of the above products or for firm price and delivery dates, please write:
HUGHES NUCLEAR ELECTRONICS MARKETING,
P.O. Box 90515, Los Angeles 45, California.

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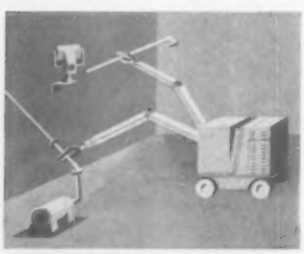
Manipulating Arm Module—Hydraulically actuated. Can execute shoulder movements—elbow and wrist rotations. Locks in any position with full load. Available in 25 & 150 lb. load capacities and 3′ and 5′ arm lengths. Power Unit (not shown) may be located outside operating area. TV is an optional module.

Control Console Module—Small and portable, it controls all moving parts of the MOBOT system. Designed to accommodate additional controls if system is expanded.

TYPICAL APPLICATIONS

Below are typical examples of how standard Hughes Mark 1-B modules can be assembled to meet your specific remote handling needs:



BIG—BUT TAKEN IN STRIDE BY B-L-H's FABRICATING TEAM

Fabricating jobs like the nuclear reactor being installed for the AEC at Hallam, Nebr., are no strangers to B-L-H. We have handled such tasks many times.

To get an idea of what's involved, note these facts about the Hallam reactor:

Reactor vessel

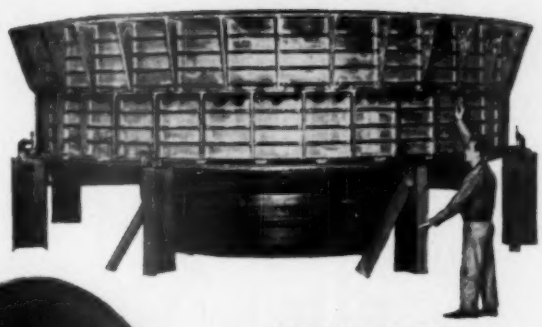
- 19 ft. in diameter, 33 ft. high, welded of Type 304 stainless steel
- Metal thickness range from ¾ to 2 in.
- All material subject to ultrasonic inspection; all welds inspected radiographically, also with dye penetrant and helium leak detection equipment

Reactor containment vessel

- 21 ft. in diameter, 36 ft. high
- Bottom head fabricated of carbon-silicon steel, main barrel section of chromium molybdenum steel
- All welds radiographed, bottom head section stress relieved

Keep in mind, too, the fact that for parts as large as these —and with the limited amount of machining—the tolerances call for highest accuracy in fabrication.

Handling big fabricating jobs economically and efficiently is our stock in trade. So take advantage of our exceptional experience and competence. Consult us about your next project and write now for a copy of our illustrated Weldment Bulletin 7001.



Loading face shield shell of Hallam reactor being check-fitted to upper cavity liner

X-ray inspection at B-L-H's Industrial Equipment Division of weld joints in lower shell course of containment vessel for the Hallam, Nebr., nuclear reactor designed by Atomics International

BALDWIN · LIMA · HAMILTON

Industrial Equipment Division · Philadelphia 42, Pa.

AT FERNALD PLANT OF

NATIONAL LEAD COMPANY

...FURTHER INDICATION OF STOKES VACUUM FURNACE VERSATILITY

Stokes Vacuum Induction Furnace casts uranium ingots at the Fernald plant of National Lead Company.

This versatile Stokes Vacuum Induction Furnace is being operated at the Fernald Plant of the National Lead Company in Cincinnati, Ohio, for the Atomic Energy Commission. Large uranium ingots, for a wide variety of special metallurgical examinations, are being cast in this facility. The consistent long term performance of this furnace has again confirmed the Stokes world-wide recognition as manufacturers of highly reliable, rugged vacuum furnaces for nuclear use.

Pumped by a Stokes Mechanical Booster, the furnace operates in the low micron pressure range. The bottom rollaway configuration is just one of the many standard designs offered by Stokes. Typical of Stokes single source responsibility is the fully integrated 200 KW induction power supply for melting and mold heating.

Why not investigate how Stokes vacuum know-how can assist your program? Whatever your requirements, the inherent flexibility of Stokes design concepts is assurance that your stringent needs can be met. Contact Stokes today.

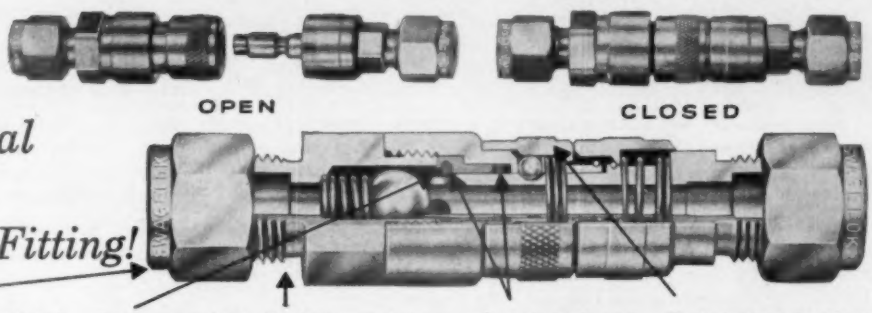
Vacuum Metallurgical Equipment Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

What's the secret of this fast, positive-seal fitting?

Swagelok Quick-Connect Fitting Installation in Boeing Airplane Company, Seattle, Wash., Test Facilities for Boeing 707 Jet Stratoliner.

Here's the secret of this fast, positive-seal Swagelok Quick-Connect Fitting!



1. Swagelok Quick-Connects with single end or double end shut off for tube to pipe, tube to tube, bulkhead tube to tube applications are available in brass and stainless steel in sizes for ¼" and ⅜" O. D. tubing.

2. Flow resumed instantly and vacuum tight seal assured when connection is made.

3. Light, compact, streamlined design. Occupies little space. For use with portable equipment, and bulkhead or panel applications.

4. Instant-acting seals completely prevent loss of pressure when fitting is disconnected.

5. No twisting, turning or wrench action necessary. Easy straight-line finger tip pull or push action for instant connecting or disconnecting.

In the Boeing Airplane Company photo shown above, the tubes are instrumentation pressure lines running from the large jet engines on test stands to the patch board, where the lines are coupled into measuring devices.

The Boeing Airplane Company adopted this positive Swagelok Quick-Connect Fitting to simplify test installations, and substantially cut down test set-up time. Both ends of the many pressure lines are Swagelok-equipped. Previously, engineers used a screw-type fitting which required a wrench and valuable time-consuming operations to tighten and remove.

Swagelok engineers are equipped with experience, ability, and a wide range of tube fittings designed to meet your individual problems. Quick delivery of Swagelok tube fittings from local distributor stocks.

Swagelok® TUBE FITTINGS

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Crawford Fittings (Canada) Ltd., Niagara Falls, Ontario, Canada

Focal Point for Nuclear Engineering

The John Jay Hopkins Laboratory for Pure and Applied Science is the focal point of General Dynamics' General Atomic Division in San Diego, California . . . a modern center where strong engineering and developmental activities are combined with broad basic theoretical and experimental research . . . an ideal environment for productive efforts in the fields of nuclear engineering and science.

Here, advanced work is underway on the High Temperature Gas-cooled Reactor (HTGR), which promises to be a major short cut to the nation's goal of economic nuclear power. The prototype HTGR plant will be completed in 1963 for Philadelphia Electric Company and High Temperature Reactor Development Associates, Inc.

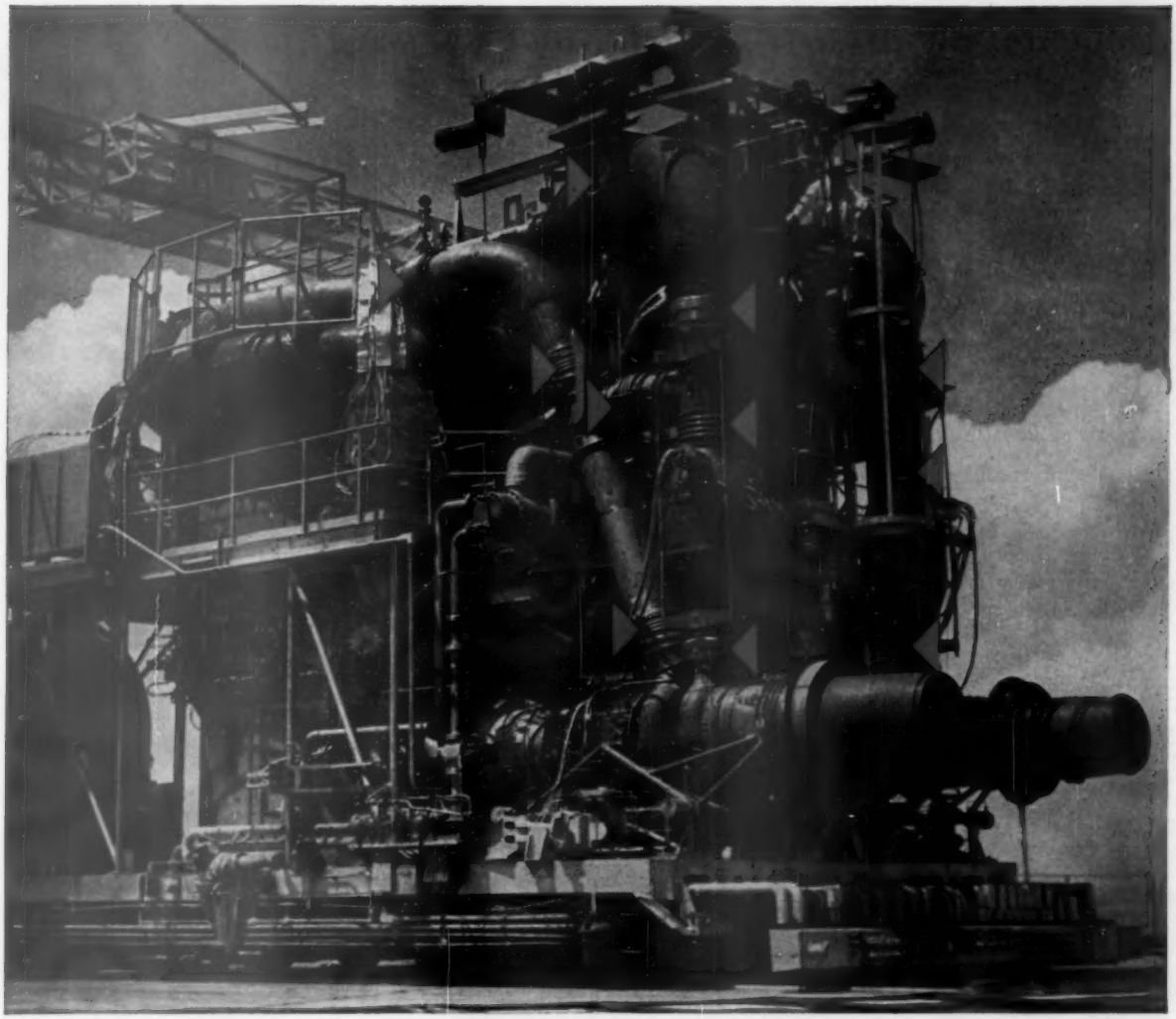
Here, engineers and scientists work in a creative atmosphere in other advanced activities, including the MGCR gas-cooled reactor and closed-cycle gas turbine system for merchant ship propulsion . . . TRIGA reactors for training, research, and isotope production, which are now being installed on five continents . . . small nuclear power systems . . . test reactors . . . nuclear power for space vehicles . . . thermoelectricity . . . controlled thermonuclear reactions.

Rapid expansion of these programs has created openings, including senior positions, for experienced engineers and scientists who seek a high degree of individual responsibility together with unusual opportunities to demonstrate their initiative and ability. In engineering, for example, immediate openings now exist for nuclear engineers to work on the following programs:

- Reactor core design and thermal analyses.
- Reactor design neutronic calculations.
- Analyses of reactor and system controls.
- Evaluation of economics associated with reactor core design.
- Operation and analysis of critical experiments and applications of results to reactor design problems.

In addition to positions for Nuclear Engineers, openings also exist for qualified Chemical Engineers, Metallurgists, Mathematicians-Programmers, and Experimental and Theoretical Physicists. Please address your letter of inquiry to Manager of Personnel, General Atomic, P.O. Box 608, Dept. 10, San Diego, California.

GENERAL DYNAMICS
GENERAL ATOMIC DIVISION



Where expansion joint reliability really counts... YOU FIND ZALLEA

Eighteen Zallea Expansion Joints protect all the piping between compressor, reactor and turbine in General Electric's Heat Transfer Reactor Experiment (HTRE). Sizes range from 18-in. to 30-in. diam. Temperatures are 500 F and 1500 F at 53 psig.

Objectives of HTRE were to develop and test a complete aircraft nuclear power plant system, to determine operating characteristics, and to verify the design of a direct-air-cycle nuclear propulsion system. As in any research involving unknown quantities (in this case the heat source) a basic requirement for all system components was *maximum reliability*. The results of HTRE were successful. Objectives were accomplished. The integrity and life of all system components were verified.

This is another example of Zallea competence in the nuclear field. In fact, Zallea has provided the large majority of all the expansion joints used in atomic, nuclear and missile projects. Our work with almost every major engineering and manufacturing firm in these fields has given us an unequalled background of experience and engineering capacity. It can give you important savings in time and investigation when expansion is involved in piping systems or tanks.

Write for Catalog 56, which contains complete and comprehensive engineering data for Expansion Joints from 3-in. to 50-ft. diam., pressures to 3600 psi, temperatures to 1600 F.

ZALLEA BROTHERS, Taylor and Locust Streets, Wilmington 99, Delaware.

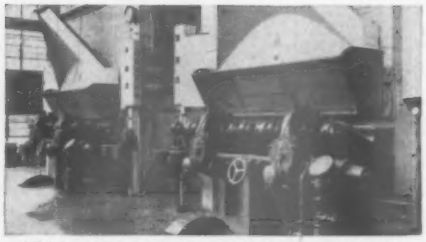
Zallea FOR MAXIMUM RELIABILITY

WORLD'S LARGEST MANUFACTURERS OF EXPANSION JOINTS

How Hagan Contributes

40 years of control and water technology experience

to Atomic Power Plant Development



1918 tea kettle boiler with Hagan Controls.

Now under construction, TVA's Widows Creek Unit No. 7, one of the world's largest steam boilers (3,850,000# steam/hr) will have Hagan controls, instrumentation and data processing systems.

Power plants have been Hagan's main interest for over 40 years. From the days of the "Tea Kettle" to the modern high temperature, high pressure boiler, Hagan control equipment and engineering know-how have contributed materially to power plant efficiency. Hagan also designs and manufactures high accuracy, solid state data handling and temperature monitoring equipment.

Originally established to deal with boiler water problems, the Hall Laboratories division of Hagan has extended its water management activities to all phases of the procurement, use, and disposal of industrial water.

Today, these highly developed skills are being applied to similar problems in nuclear power plants. Here are a few of the areas in which Hagan control engineering, or Hall's ability to make water behave predictably have served the nuclear field:

Temperature measurement on the sodium purification loop on an experimental nuclear reactor . . . mass flow metering on a gas-cooled reactor loop . . . condenser protection relief system on a reactor power plant . . . steam pressure control system for first nuclear powered commercial vessel . . . consultation on water treatment for a pressurized-water and a homogeneous reactor . . . materials specification and water treatment for an electron accelerator cooling system . . . steam quantity tests on nuclear submarines.

The specialized chemical experience of the Calgon Company, another Hagan division, is also available to aid in specific water problems such as corrosion, deposition and cleaning.

A separate, highly qualified Hagan organization—the Nuclear Power Division—coordinates all Hagan activities in the atomic power area. For information on the application of Hagan equipment and services to atomic power plant development, write or phone NUCLEAR POWER DIVISION, ROOM 808, HAGAN CENTER, PITTSBURGH 30, PENNSYLVANIA.

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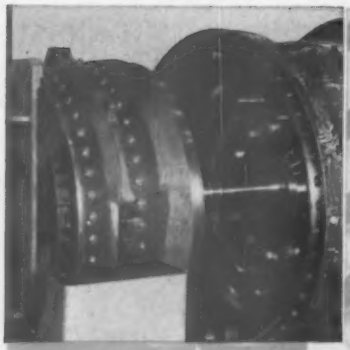
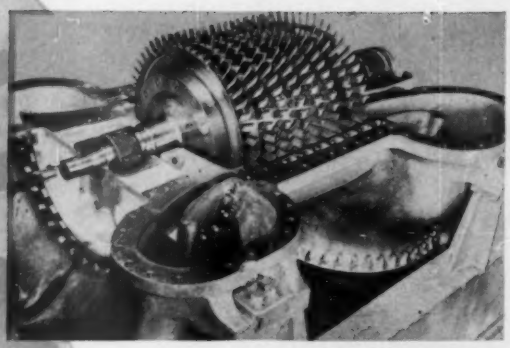
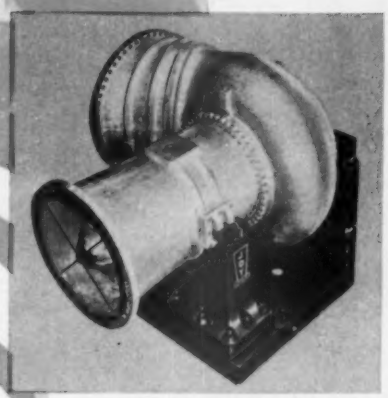


Assembly of Barrel Compressor.



15,000 hp multi-stage axial flow compressor.



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For complete details on Joy gas circulating compressors, write for Bulletin 1282-92.

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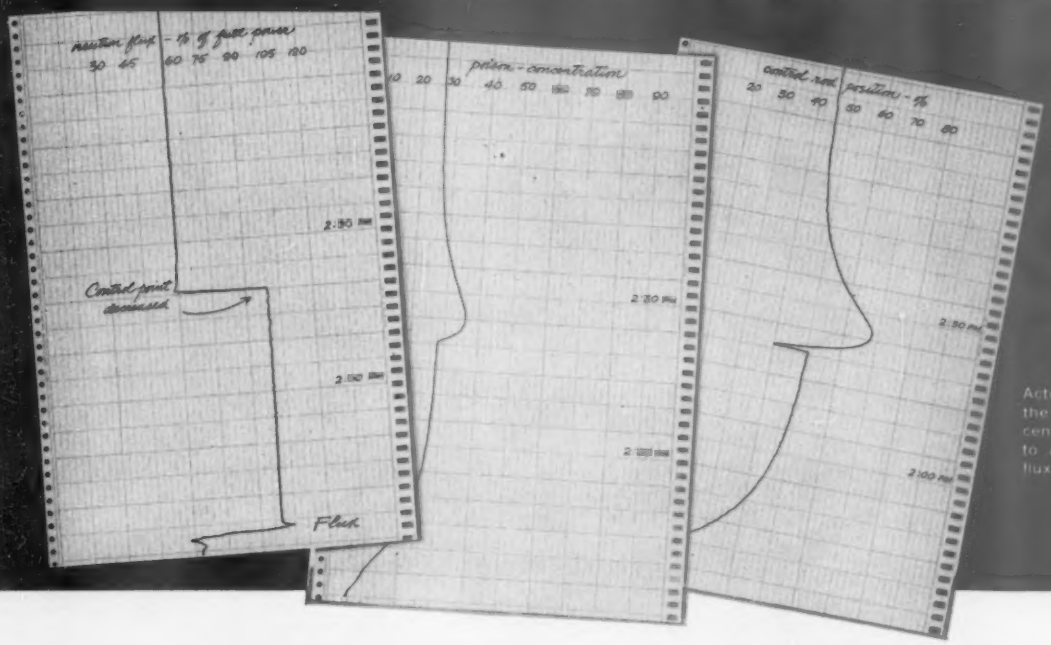

Actual chart records show the response of poison concentration and control rod to a decrease in neutron flux control set-point.

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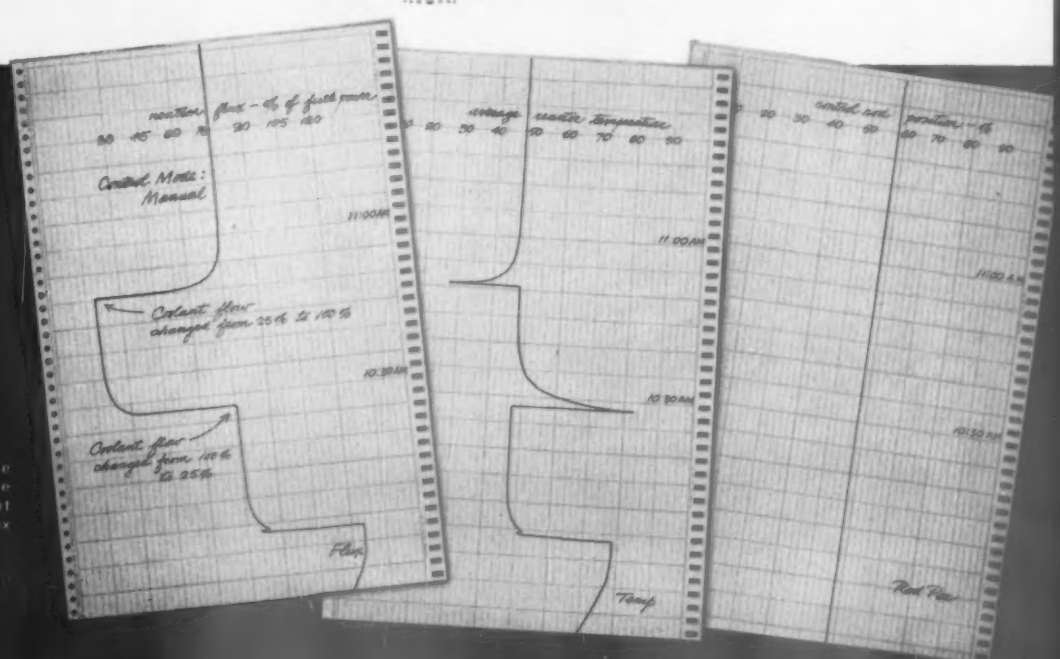
neutron flux - % of full power
Control Mode: Manual
Coolant flow changed from 25% to 100%
Coolant flow changed from 100% to 25%
Flux
average reactor temperature
Temp
control rod position - %
Rod Pos

These records show the stabilizing effects of the average reactor coolant temperature on neutron flux with manual control.

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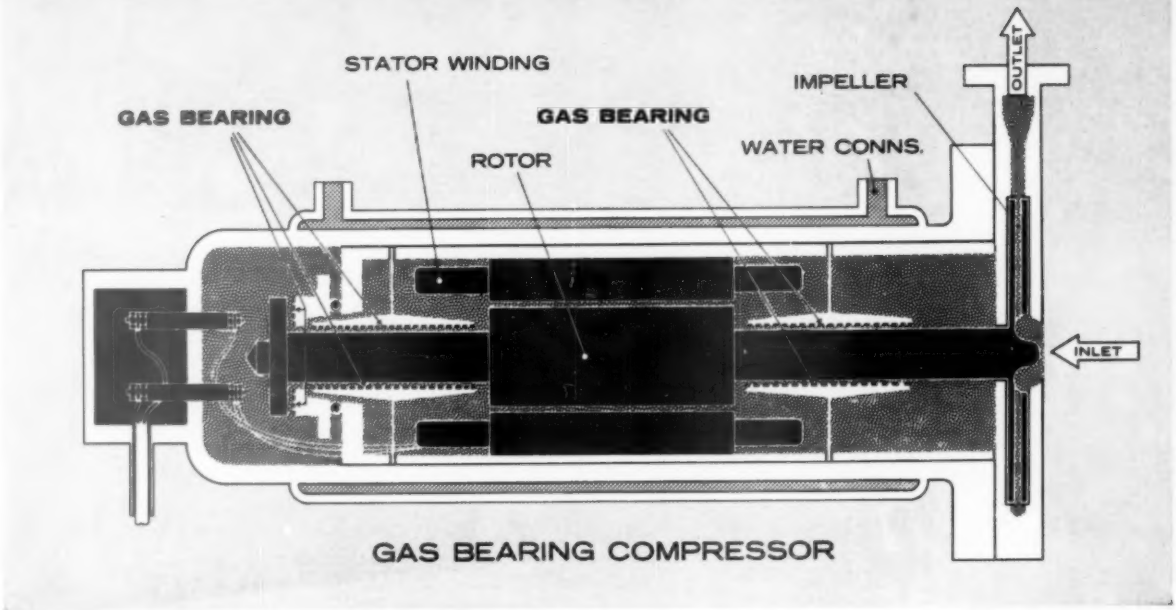

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For information about Bristol Siddeley gas-bearing compressors and gas bearings, please write Bristol Aero-Industries Limited, 200 International Aviation Building, Montreal 3, Canada.

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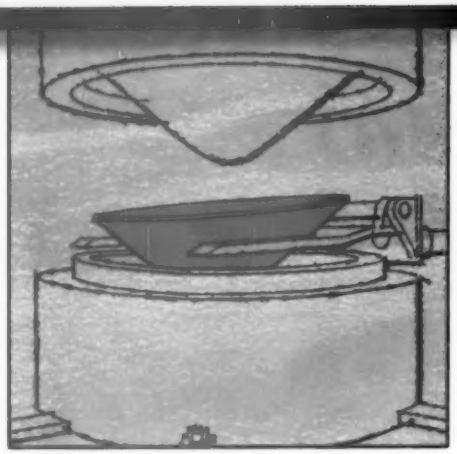

Nose cone being removed from Wyman-Gordon-U.S.A.F. forging press.

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Inspection of copper nose cones at Wyman-Gordon-U.S.A.F. Plant.

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The "slave-hands" of an AI technician handle radioactive materials through a hot cell window 3½ feet thick. *Woodcut by Edward Kysar.*

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With some of the most sophisticated facilities in the world at their disposal, the men at AI are now conducting studies for large power station reactors in the United States and Europe. Two reactors are now actually under construction under AEC programs—an Organic Moderated Reactor in Piqua, Ohio, and a Sodium Graphite Reactor in Hallam, Nebraska. Smaller research reactors have been built by Atomics International for Denmark, Germany, Italy, Japan, Puerto Rico and several sites in the U.S.A.

For details contact: ATOMICS INTERNATIONAL, Canoga Park, California, U.S.A. Cable address: ATOMICS.

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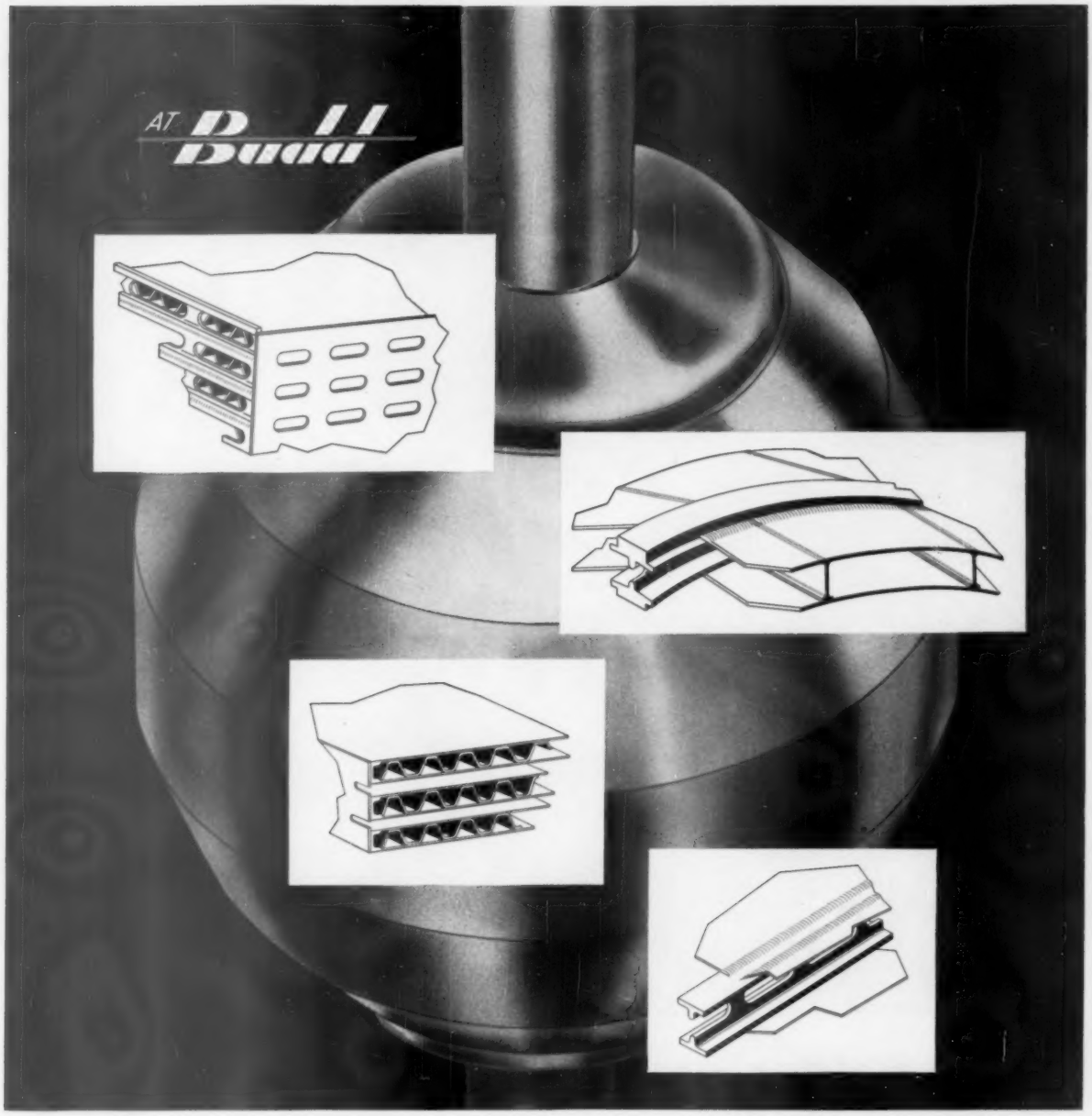

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Photo by General Dynamics

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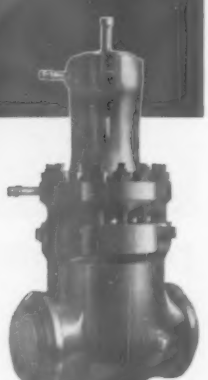

Darling stainless steel gate valve.

**The nuclear reactor for the Skipjack was designed and developed by the Bettis Atomic Power Laboratory. Westinghouse operates the Bettis Laboratory for the U. S. Atomic Energy Commission under the direction of and in technical cooperation with the Naval Reactors Branch of the AEC.*

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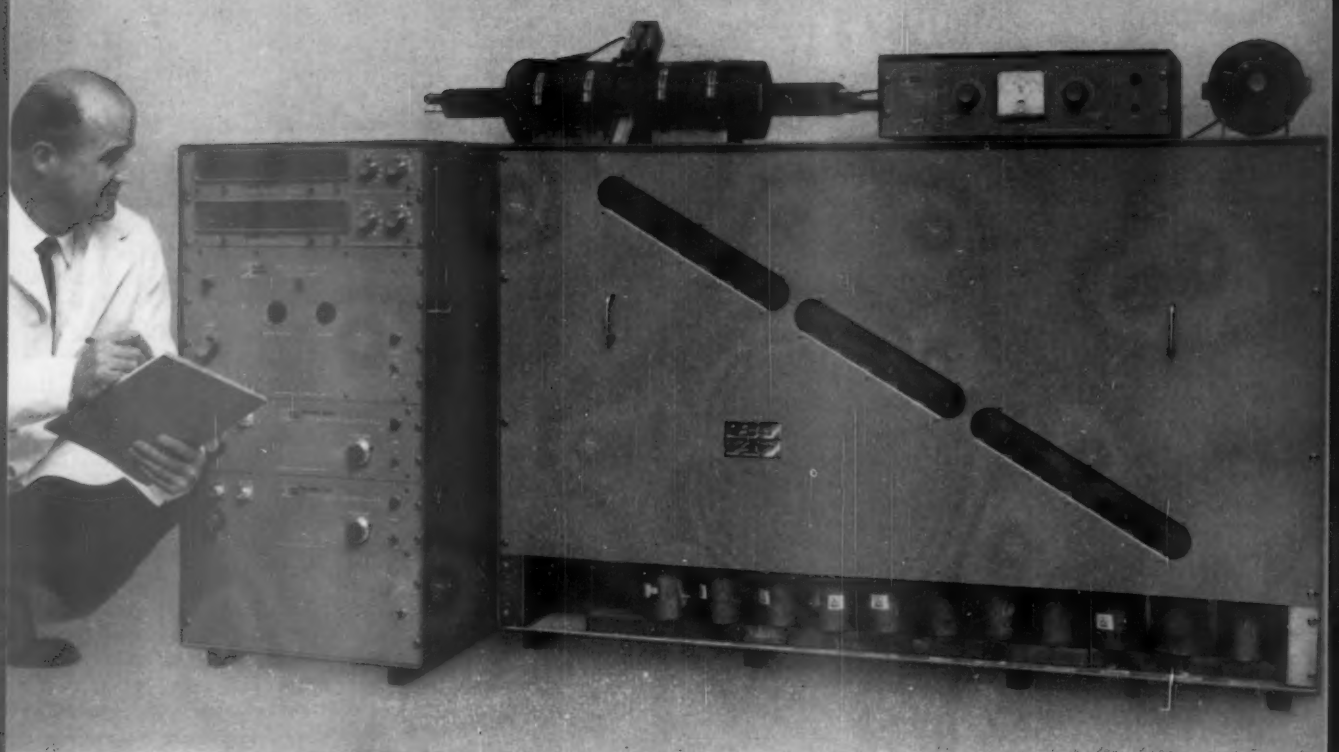

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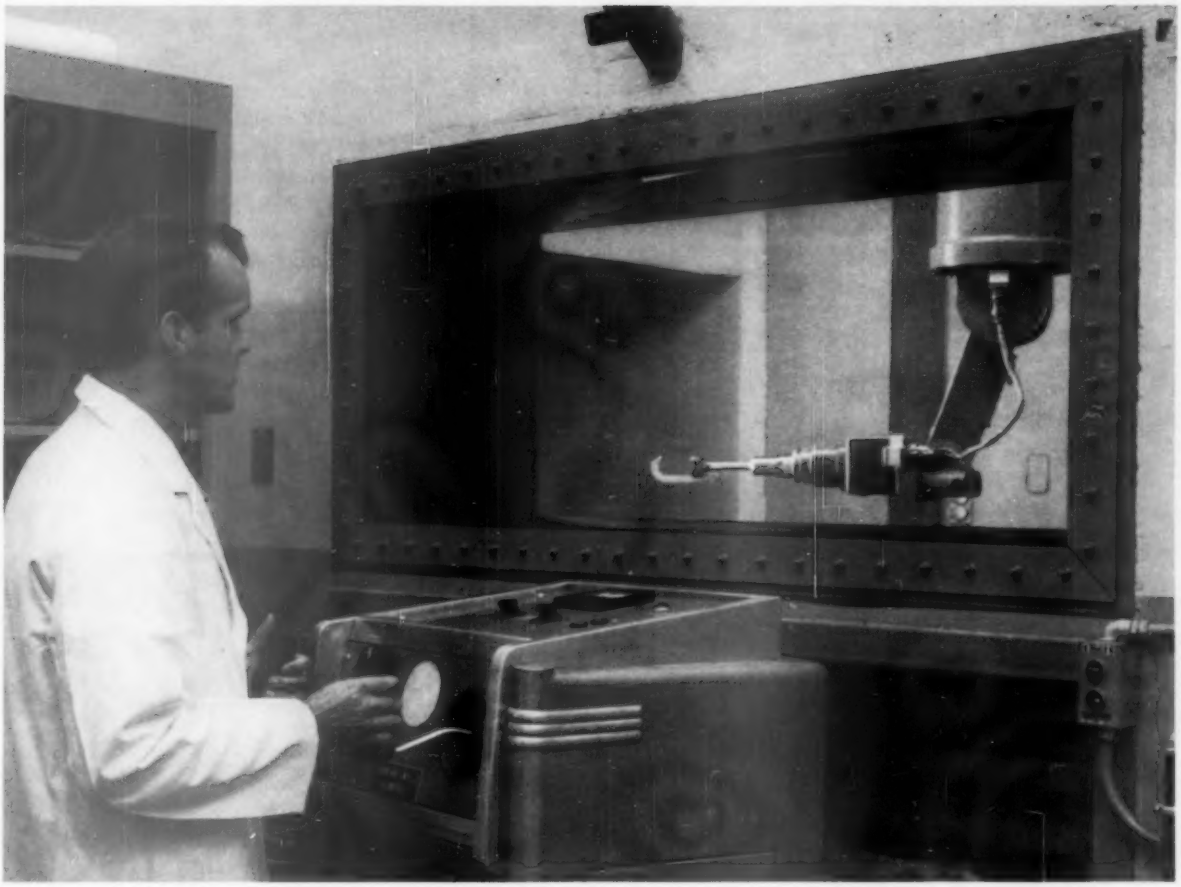

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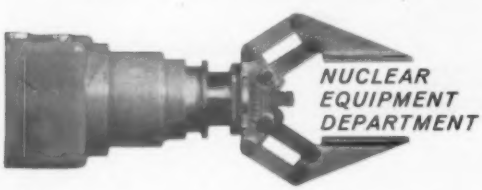

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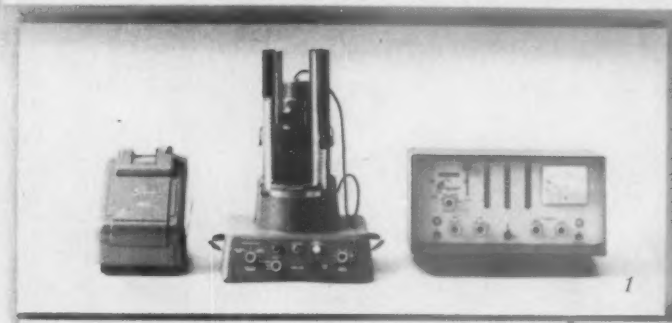

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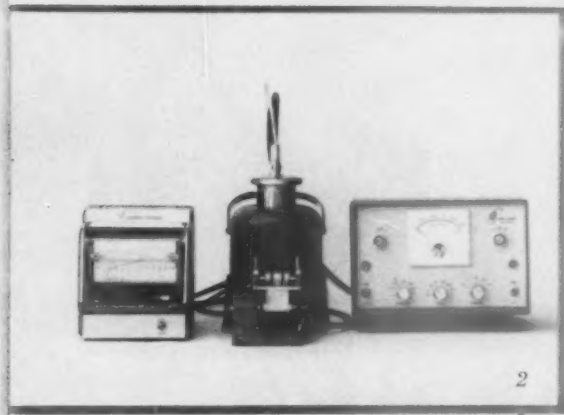

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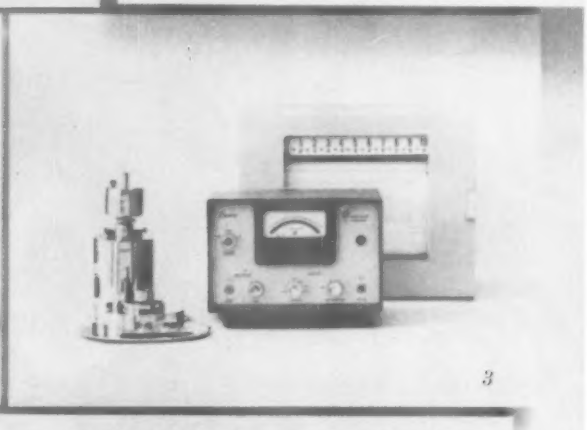

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NUCLEONICS

JEROME D. LUNTZ, *Editor and Publisher*

MAY, 1960

Army and Space Reactors

THE NAVY REACTOR program is the only part of the U. S. reactor effort that has consistently had a sense of purpose and direction. As a consequence, its achievements have been phenomenal, and the U. S. is unquestionably leading the world here.

Civilian nuclear power, on the other hand, has never really had any strongly motivated drives behind it. Thus, it has meandered along.

It is easy to see these things in retrospect. But now, as we stand on the edge of entering new frontiers in other reactor fields, it is possible to make use of our past experience and point out that unless we light a fire under some of our newer programs there will be a serious danger of meandering—to the point where, five to ten years from now, we'll look back with regret.

Two such reactor programs are the Army and space efforts. Both have been rather modest in size to this point. And, it is now clear, both are inadequate, totally inadequate, if the U. S. is to forge ahead imaginatively and boldly in these areas.

THE ARMY PROGRAM to date, which has been a poor cousin of the reactor field, financially speaking, has been a successful one technically. A great deal has been learned about the operation, engineering and economics of compact water reactors that shows they are admirably suited to meet the power requirements of remote bases. It had originally been thought that reactors of this size (less than 2,000 kwe) would only be justifiable for a long time to come on logistic grounds—to make the Army (and other services) independent of long fuel-oil supply lines.

But now, studies show that a several-thousand-kw pressurized-water plant would be competitive with oil-fired plants in about two years after the nuclear plant went into operation in the Antarctic.

Despite this, the Pentagon—either because of a nuclear inferiority complex or because of technical and budgetary conservatism—has not seen fit to ask for funds to make history at the Antarctic. Instead, the Joint Committee on Atomic Energy finds itself in the peculiar role of pleading with the Pentagon to ask money of the Congress.

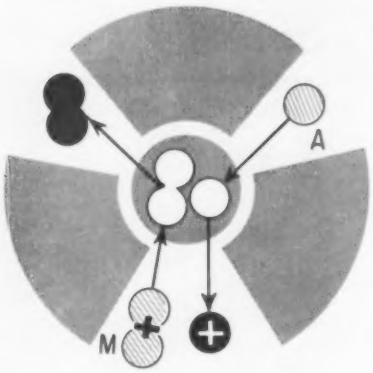
IN THE SPACE FIELD, although the technology is not similarly advanced, the opportunity for capturing world leadership is present too. But again, perhaps this time because the responsibility is spread among several different government agencies, aggressive and unified leadership has been absent and the program has consequently been a leisurely, seemingly unmotivated one.

The nuclear reactor space effort has centered around the Project Rover rocket work and the SNAP (Systems for Nuclear Auxiliary Power) program. This work has already shown quite clearly that nuclear energy is the only hope for conquering space—for getting vehicles into deep space, maintaining them there, providing a variety of communications services from space, and achieving interplanetary travel.

But firm and early contract dates have not been established. Even as the nuclear-aircraft effort has floundered and is now in an almost hopeless state, so these efforts will suffer unless strong direction is given.

This applies to both the Army and space reactor work. Leadership for the U. S. is within reach in these pioneering fields. With unquestioned support from Congress already indicated, the Administration must quit shuffling its feet and see that work moves ahead at a rapid, clearly defined pace.

Chemical Protection from Radiation Effects



Some substances prevent undesirable reactions, and others promote beneficial ones. Comparing chemical structures may show why and how

By DONALD R. KALKWARF
Hanford Laboratory, General Electric Co., Richland, Washington

CHEMICAL PROTECTION of irradiated systems and chemical promotion of radiation effects are outstanding accomplishments of the study of radiation chemistry and biology. By addition of selected chemicals one can hope to reduce hazardous effects of ionizing radiation to man, protect exposed materials from damage and improve yields of radiation-induced reactions.

Although absorption of ionizing radiation is not particularly dependent on chemical structure, subsequent utilization of deposited energy varies considerably with absorber structure and environment. The basic problem is to manipulate these factors so as to facilitate some reactions and retard others. Fortunately the molecular events during irradiation are involved enough to be deflected at several different stages by added reagents.

Protection, Restoration

Protection has various meanings depending on whether one takes a macroscopic or microscopic view of irradiated material (*1–3*). Within a system, ionized and electronically excited structures decompose spontaneously, react chemically with their neighbors and transfer energy to them. Subsequently decomposition and reaction products react with other constituents until an ultimate composition is attained. One can maintain or create desirable properties of the system by preventing decomposition of certain molecular components present initially or formed during irradiation. This is what we mean by "protection."

There are also systems in which one can maintain desirable properties by regenerating components destroyed by radiation. This is termed "restoration." Often it is difficult to distinguish between protection and restoration; a reagent may accomplish both.

Chemical agents can also increase (promote) the apparent effects of irradiation.

Prospects for Protecting Humans

World-wide research effort is looking for ways to protect human beings chemically from effects of ionizing radiation. It is now certain that radiation death of experimental animals can be inhibited by pretreatment with certain compounds. In general, protected animals can tolerate up to twice as much absorbed radiation as can those without protection. At present chemical protection from genetic damage, however, does not appear successful.

Application of currently known protective agents to humans is limited by their high toxicity and short effectiveness—only a few hours. But use of such compounds would certainly be indicated in emergencies such as war, accidents in nuclear-energy plants or entrance into unforeseen radiation zones of outer space by travellers of the future.

A more routine application is in radiation therapy. If healthy parts of the body can be protected from damage, larger radiation doses can be used to treat malignancies and the problem of shielding the patient during treatment is reduced.

Some success has already been noted with tumor-bearing mice pretreated with AET (59) and humans pretreated with cysteamine and cystamine (61).

Oral introduction of AET has been found to be as effective as intravenous or intraperitoneal injections in mice and monkeys (35, 55) and to provide the longest protection. Nevertheless, a maximum oral feeding is totally effective only if given less than 6 hr before exposure to 900 r (35). The protective ability of AET in other mammals is subject to question (56, 57), and in humans it is unknown. The biological half-life for renal excretion of this compound and its decomposition products in humans is only 12–16 hr (58); so its actual period of effectiveness may be considerably less. Preliminary toxicity tests of AET on humans indicate that even 10^{-5} moles/kg of body weight can produce nausea and rash in some patients (59). This may be a small cost for the protection as compared with some alternative consequences. Ingestion of up to 800 mg of cystamine or intravenous injection of 400 mg of cysteamine ($\sim 4 \times 10^{-5}$ mole/kg of body weight) has been suggested for human protection in case of emergency. The effect would probably last only a few hours (60).

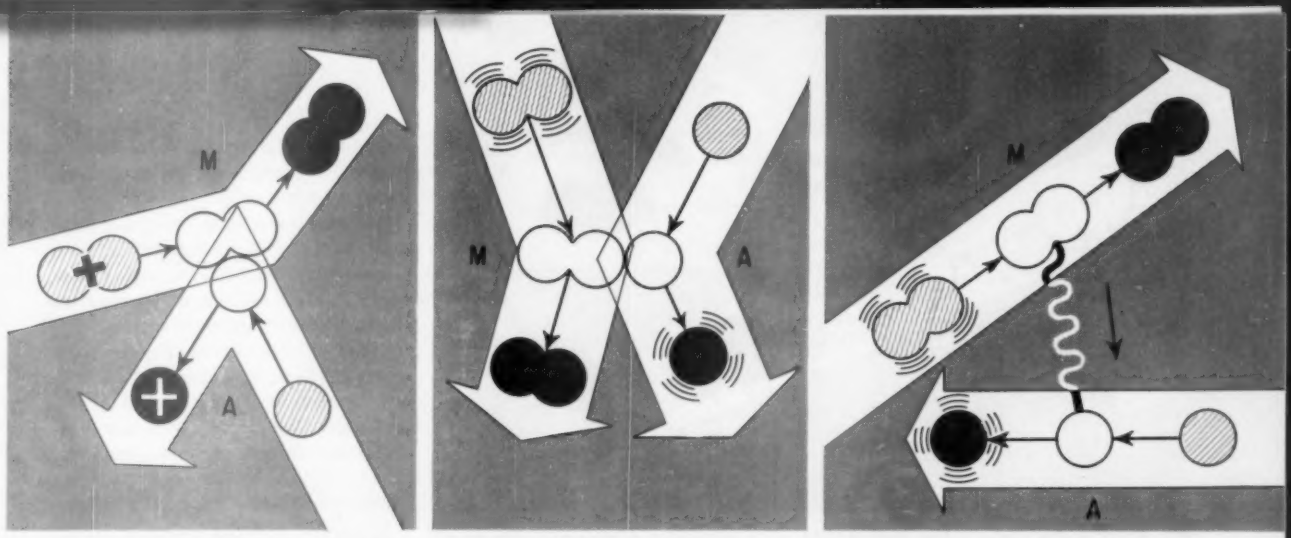


FIG. 1. ENERGY AND CHARGE TRANSFER to an additive can protect a molecule exposed to radiation. Three modes of transfer are (a) charge exchange in a collision, (b) excitation exchange in a collision and (c) resonance excitation exchange at a distance. To be effective, processes must be fast enough to compete with dissociations that cause damage

MECHANISMS

On a microscopic scale there are several mechanisms (some hypothetical and some confirmed) which increase and decrease radiation effects:

Energy and charge transfer. An ionized or excited molecule transfers its charge or excess energy to a reagent molecule either by collision or by resonance transfer at a distance.

Scavenging. Molecules initially absorbing the radiation decompose, but additives react rapidly with the decomposition products and prevent them from attacking other molecules.

Complex formation. An additive can form complexes that are either more or less susceptible to radiation than the original substance.

Energy, Charge Transfer

One method of protecting an ionized or electronically excited molecule from decomposition is to enable it to transfer its charge or excess energy to an added reagent. Such a transfer must be fast enough to compete with dissociation processes. In some cases, the activated molecule can dissociate within 10^{-14} sec, but usually localization of enough energy in a particular bond requires a much longer time (typically 10^{-13}–10^{-9} sec).

Figure 1 shows several types of proposed transfer mechanisms. To remove energy efficiently from the activated molecule, the additive should have a slightly lower ionization or excitation potential (*4*). In fluid systems the speed of charge transfer is limited by diffusion; the donor and acceptor must be in contact. Excitation energy, however, can be exchanged between molecules separated by as much as 70 A through resonance transfer (*5, 6*). One of the requirements of this process is a partial overlap between the absorption spectrum of the acceptor and the emission spectrum of the donor, despite the fact that the transfer is "radiationless." The process occurs much more rapidly than ordinary fluorescence and thus competes more favorably with dissociation.

In some ways transfer processes occur more efficiently in rigid systems. Order in crystalline material allows excitation energy to move in "excitons," which can traverse the crystal faster than its vibrational relaxation time (*7, 8*). Crystalline structure also facilitates charge transfer by providing conduction bands in which electrons can easily travel far (*8, 9*).

Energy conversions within a molecule can decrease the probability of decomposition; energy can be distributed so widely that its localization in any one bond is improbable. Paramagnetic additives or those containing atoms with strong nuclear magnetic fields can promote this wide distribution by extending the number of energy states available to the original molecules. Ordinarily transitions between energy states of different multiplicity are not probable, but proximity of strong magnetic fields can remove this forbiddenness (*10*). This protective effect of an additive can also occur rapidly and compete with dissociation processes (*11*).

How we know. Many laboratory experiments provide evidence of energy and charge transfer in irradiated systems. For example, a 32% reduction in the polymerization of irradiated acetylene is achieved by adding benzene vapor in a 1:3 mole ratio (*12*). This is a rather convincing example of charge transfer: the polymerization-inhibiting benzene has a lower ionization potential than acetylene; conversely additives with higher potentials promote polymerization (*13*). Formation of hydrogen from decomposition of liquid cyclohexane is reduced 10% by 10^{-3} M benzene (*14, 15*). Similarly addition of perdeuterobenzene protects benzene during gamma irradiation (*16*). Even in these simple systems, however, it is difficult to distinguish particular types of transfer processes; several may be occurring simultaneously.

There is considerable evidence for energy and charge transfer in irradiated solids. The radiation resistance of the enzyme catalase in the dry state is almost doubled by adding 2% glutathione (*17*). The main chains of polymethylmethacrylate are protected from scission by small amounts of various compounds dissolved in the polymer to form a solid solution (*18*). For example, the energy required to break a chain in the presence of 10% di-*m*-tolylthiourea was increased by a factor of almost 4. Even water bound to polysaccharides appears to accept

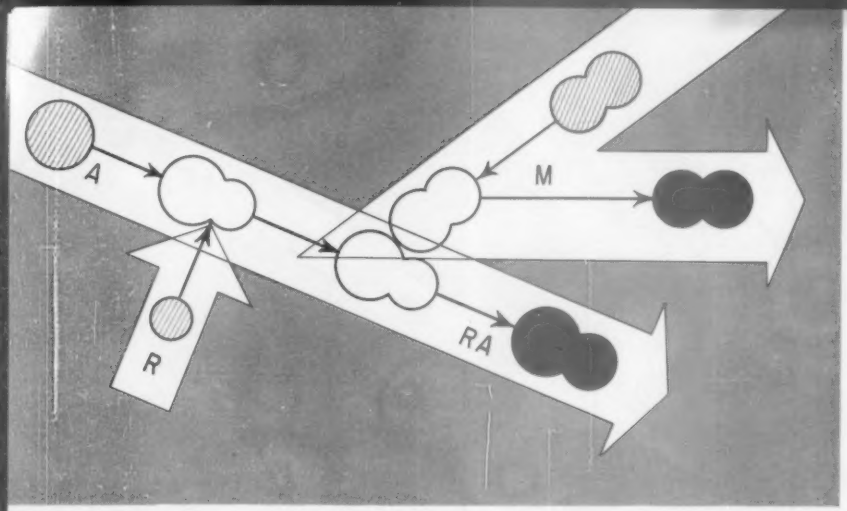


FIG. 2. SCAVENGING OF REACTIVE SPECIES by an additive is another mode of protection. The reactant R combines with additive A to form a nonreactive complex RA. Collisions between complex and protected molecules fail to produce the damage that would occur in molecule-reactant collisions without the additive

energy from the main chains, preventing their degradation (*19*).

Scavenging Intermediates

Even though the molecules initially absorbing the radiation decompose, the system as a whole can be largely protected by inhibiting secondary reactions caused by decomposition products and other intermediates (Fig. 2). Additives that react rapidly with these substances can sacrificially prevent their attack on other molecules in the system. The amount of protection depends on both additive concentration and ability to react with an intermediate on collision. Structural features that enhance ability to react are of particular interest (*20*); one would like to protect large amounts of material with little additive.

In general, free radicals are the most reactive class of decomposition products, and free-radical scavengers offer potent protection. Attack on the enzyme carboxypeptidase by radicals formed during the irradiation of water was early shown to be modified by the presence of other solutes (*21*). Likewise protection of polymethacrylic acid (*22*) and the dye erioglaucine (*23*) in aqueous solution was achieved by adding a wide variety of compounds.

The inherent ability of compounds to react with radicals varies widely. Thiourea, for example, was found to react 2,000 times as rapidly as the same concentration of urea (*21, 23*). Numerical comparisons in series of related compounds help determine which modifications produce the best scavengers.

Oxygen, being a diradical, can become an important intermediate in promoting radiation damage. It reacts rapidly with other radicals to form peroxy radicals; these in turn attack compounds to form new free radicals and reactive peroxides (*24*). Other additives react selectively with molecular oxygen and peroxides; in fact, inhibitors usually present in commercial hydrogen peroxide limit its use in duplicating hydrogen-peroxide effects produced by irradiation of water (*25*).

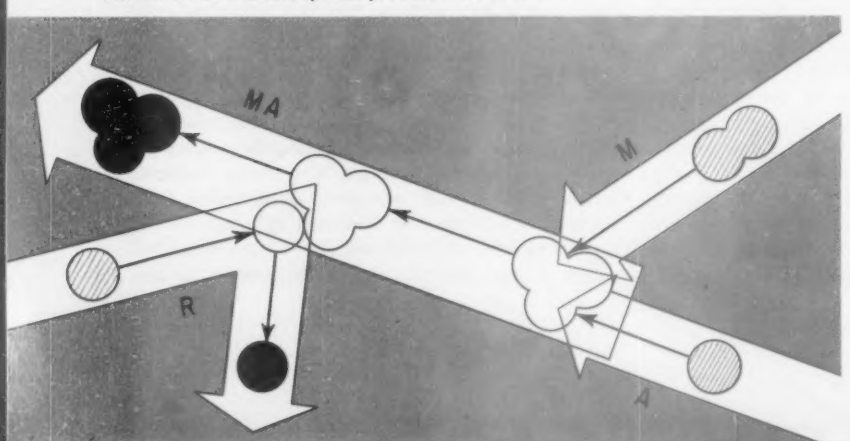
Electrons are also potent reactants. Since positive ions are initially formed in excited states, neutralization of one of them with an electron produces an excited molecule that can decompose. It has been suggested, however, that if a neutral additive can first capture the electron, it can in turn neutralize the positive ion with less chance of molecular decomposition (*2*).

Complex Structures

An additive can also protect a compound by forming a molecular complex with it, as shown in Fig. 3. The new structure may transfer energy and charge better and be less susceptible to attack by radicals and other decomposition products. Protection can also result from formation of complexes across particularly sensitive bonds in the original compound.

Several examples definitely suggest this kind of protection. Degradation of polyisobutylene is reduced almost 50% by copolymerization with 20% styrene (*26*); the enzyme deoxyribonuclease is protected by the presence of its substrate, deoxyribonucleic acid (*27*); and the radiation resistance of the porphyrin ring is increased by complexing with vanadium and other metals (*28*). Complexing the enzyme tyrosinase with one of its substrates improves its resistance to free-radical attack in aqueous solution (*29*).

FIG. 3. MOLECULE-ADDITIVE COMPLEXES may also have a protective action. Molecule M combines with additive A to form a particularly stable complex MA, which remains unaffected in collisions with reactant species R. Without additive, collisions between molecules and reactant species produce more reactants



BIOLOGICAL PROTECTION

The prime goal of most research with chemical protective agents is to decrease effects of ionizing radiation on living systems, particularly man (see box, page 76). Most investigations are concerned with protection of laboratory animals, usually mammals, from death caused by an acute total-body irradiation. Other biological organisms and methods of irradiation also provide valuable information. Extrapolation of the results to man is still a critical and uncertain step.

A useful protective agent in living systems must meet several criteria. One of the most important is that it be nontoxic at protective concentrations. It should also (a) be easily introduced, (b) become widely distributed and (c) remain intact for a long time before irradiation.

Research. Some idea of the extent

of research with chemical protective agents on living systems can be had from Table 1.* The table groups chemically similar compounds tried recently and represented as having a protective effect in the references cited. Earlier references are compiled elsewhere (*30*). Although extensive, this table is undoubtedly incomplete and contains compounds considered nonprotective by some investigators. Disagreement easily arises not only from differences in species and strain of studied organisms but also from unsuspected critical influences in their treatment and irradiation.

Protective ability of compounds has been measured in various ways. Survival protection is often expressed as the percentage of animals treated with a subtoxic amount of the compound which are alive 30 days after absorbing the minimum radiation dose required to kill all members of a similar, untreated group. Good protective agents can be further compared by determining the minimum amount of compound required for 100% survival in such a test or the maximum increase in the $LD_{50/30}$ (radiation dose lethal to 50% of the animals within 30 days) achieved by using the compound.

Significant Agents

Despite differences in evaluation, a number of compounds stand out either because they exhibit a pronounced effect or because they suggest interesting protective mechanisms. Cysteine was one of the first compounds reported to protect living systems (*31*). The thiol (—SH) and amine ($—NH_2$) groups in this molecule have been the focus of much interest, and many other compounds containing both these groups have been examined. Among these, cysteamine and cystamine (*32, 33*), 2-mercaptoethylguanidine (*34*) and 3-mercaptopropylguanidine (*34*) have been examined most intensively. The last two compounds are normally administered as the corresponding aminoalkylisothiuronium salts (abbreviated AET and APT, respectively), which rapidly undergo molecular rearrangement to the guanidine forms at the *p*H of the body.

TABLE 1—Protective Agents in Living Systems

Group	*References*
Inorganic	
Gases	*49, 89–95*
Salts	*37, 44, 93, 96–102*
Organic	
Acids	*34, 37, 41, 51, 52, 99–101, 103–115*
Alcohols	*34, 37, 38, 99, 105, 116, 119*
Amides and amidines	*38, 131*
Amines	*34, 37, 38, 41, 50–52, 60, 99, 101, 103–112, 114–130*
Carbamates	*37, 105, 107, 117, 121, 132–134*
Carbohydrates	*37, 38, 135, 136*
Disulfides	*34, 37, 38, 41, 103, 121–123*
Ethers	*118*
Guanidines	*34, 38, 45, 55, 127, 137, 138*
Heterocyclics	*34, 37, 45, 110, 126–128, 139–144*
Hydroquinones	*138*
Isothiuroniums	*34, 38, 42, 47, 103, 116, 127, 145, 146*
Ketones	*116, 146*
Nitriles	*37, 116, 117*
Phenols	*37, 105, 119, 139, 147*
Proteins	*148, 149*
Steroids	*150*
Thiols	*34, 37, 38, 41, 50–52, 55, 103, 105, 116, 120, 121, 123–127, 132, 137, 138*
Tissue extracts	*151–153*
Tropolones	*154*
Ureas	*103, 127, 155*

The amounts of these and other compounds required to protect mice are shown in Table 2. Although the $LD_{50/30}$ for mice protected with cysteamine was increased by a factor of 2 (*32*), this compound increased the radiation resistance of the bacteria *E. coli B/n* by a factor of 12 (*35*). Similarly, AET increased the $LD_{50/30}$ for mice by a factor of 2 (*35*), but this factor was increased to 3 by coupling the treatment with bone-marrow and streptomycin therapy (*36*).

Mode of action. Essentially three mechanisms for the protective action of these compounds have been considered. They are (1) scavenging of free radicals (*37, 38*), (2) lowering of oxygen tension in tissue (*39, 40*) and (3) formation of complexes with sulfur-containing proteins by means of —S—S— bonds (*41*). Unfortunately, these processes are difficult to distinguish in living organisms.

Another significant group of protective agents includes inorganic gases such as xenon, krypton and carbon monoxide as well as pharmacologically active compounds such as histamine, 5-hydroxytryptamine, nitrite, hydrosulfite and cyanide. These are similar in their ability to lower oxygen tension of living tissue (*42, 43*). Sodium hydrosulfite increases radiation resistance of the bacteria *E. coli* by a factor of 5 (*44*). The small amount of

TABLE 2—Protective Agents and Mouse Survival

Substance	*Amount (10^{-2} mole/kg of body wt)**	*Reference*
Cysteamine	2	*37*
Cystamine	1	*37*
2-Mercaptoethylguanidine (AET)	1	*34*
3-Mercaptopropylguanidine (APT)	0.5	*34*
5-Hydroxytryptamine	0.3	*143*
Sodium diethyldithiocarbamate	2	*37*

* The amount that produces essentially 100% survival in groups of mice 30 days after absorbing the minimum radiation dose required to kill all untreated animals.

* The published version is much reduced from the author's original table. NUCLEONICS will be happy to make the original table with ~150 entries and corresponding references available to specialists who write for it.

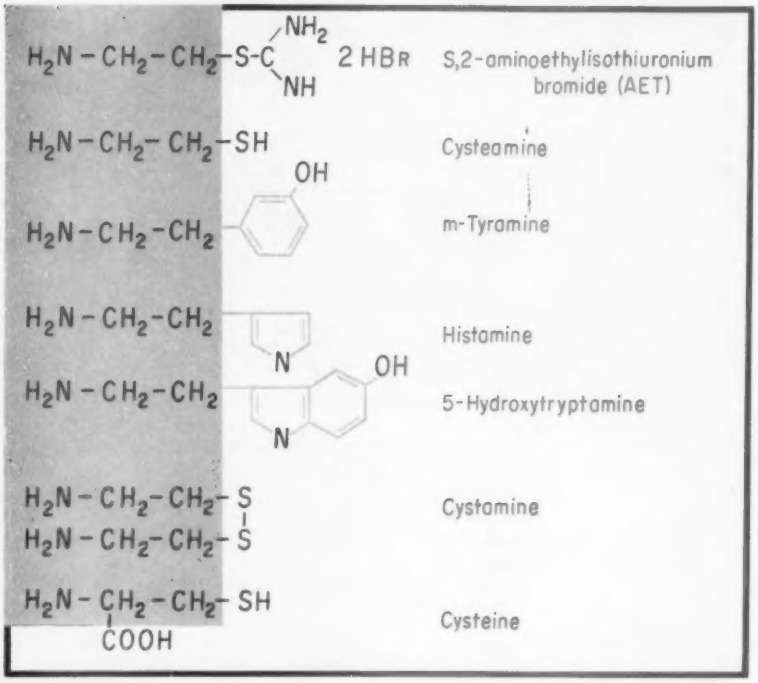


FIG. 4. RELATED CHEMICAL STRUCTURES OFTEN PROTECT. Here are several compounds that offer protection to irradiated mice. All are similar in their inclusion of beta-substituted ethylamine groups

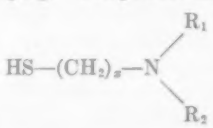
5-hydroxytryptamine required to protect mice is shown in Table 2. A related phenomenon appears to be increased survival of animals given a preirradiation injection of nembutal or barbamil since oxygen consumption is decreased during deep narcosis (*45*).

Compounds famous for their chelating ability (such as ethylenediaminetetraacetate and diethyldithiocarbamate salts) have also been found effective in protecting mammals from radiation-induced death (*37*). Again, it is difficult to determine whether complex formation is important.

Structural Requirements

Early inspections of structures that exhibit protective ability in biological systems revealed several generalities. A common feature is an unshared pair of electrons (*37*). This is interpreted as allowing the molecule to react rapidly with perhydroxyl radicals (HO_2). Some of the best protective molecules for mammals contain the thiol group (—SH); yet a large number of other molecular structures containing this group are ineffective.

A more systematic approach has been to test series of compounds with related structures. It has been pointed out that beta-substituted ethylamine groups are common to a number of good protective agents in mice (*37, 44*). Figure 4 shows several compounds with this grouping. Compounds like



offer biological protection if x does not exceed 3 and R_1 and R_2 are alkyl substituents (*46*). It has also been suggested that protective action of aminoalkylisothiuronium salts depends on their ability to rearrange into the corresponding mercaptoalkylguanidines in which a thiol group is exposed. Compounds containing two or three methylene groups can do this readily, but both the ability to rearrange and the protective ability decrease in other homologues (*35*). It was shown recently, however, that certain unsubstituted alkylisothiuronium salts that cannot rearrange are also good protective agents in mice (*47*).

Examination of series of compounds is often hampered by chemical toxicity of certain members and the delay necessary in obtaining observable effects after irradiation. For these reasons many experimenters replace living systems with inanimate chemical model systems in which effects are relatively easy to detect and interpret (*21–23*). Extrapolation among systems is always uncertain; in at least two cases, however, a remarkable correspondence has been obtained between the abilities of compounds to protect model systems *in vitro* and their abilities to prevent death (*37, 41*).

It should not be forgotten that chemical structure of an additive also determines its ability to reach the potential site of damage. Protection may require penetration of compounds into the smallest subdivisions of the cell. For example, the optical isomers D- and L-S,2-aminobutylisothiuronium bromides differ by a factor of 3 in preventing death of irradiated mice; this has been correlated with their ability to reach certain cellular constituents (*48*). The effect of the rare gases in protecting bean roots by displacement of oxygen has been correlated with their ability to dissolve in lipids. In the living organism lipids are concentrated at specific sites in the cell (*49*).

Extent of Protection

Known protective agents appear selective in their inhibition of radiation-induced effects in the body. The mercaptoalkylguanidines increase the mean longevity of animals, prevent induction of leukemia and protect against death; they do not prevent nephrosclerosis, loss of fur color or cataract formation (*34, 35*). Cysteamine protects animals from death following an acute radiation dose but does not protect against genetic damage or sterility (*32*).

In most systems, protective agents are effective only if present during irradiation. It has been demonstrated, for example, that cysteamine is ineffective in protecting mice from radiation-induced death even if given as soon as 20 sec after a 25-sec radiation exposure (*32*). Treatment of human patients with cysteamine after X-ray therapy was found to alleviate symptoms of radiation sickness (*50*), but this action was considered restorative rather than protective.

Recently it has been observed, however, that if the metabolic rate is low, protection can still be achieved shortly after irradiation. Hibernating dormice and cooled bull spermatozoa were

irradiated and kept for several weeks without evidence of radiation damage until warmed to room temperature (*51*). In addition, this damage was prevented entirely by addition of cysteine to either system immediately before warming. Similarly, inhibition of cell division in irradiated dry bean seeds allowed to sprout in a nutrient solution was prevented by addition of either cysteine or cysteamine to this solution (*52*). The protective effect decreased rapidly with time, becoming nil after 2 hr. Observations of this type strongly suggest that some long-lived intermediates produced by radiation can be intercepted before they can continue the reaction chains in a living system. Studies *in vitro* have shown that free radicals formed from amino acids and other biologically important compounds during irradiation can be maintained for several weeks if they cannot collide rapidly with other molecules (*53*). Despite the potentialities for after-irradiation protection, however, there is no agreement about this effect in living systems (*54*).

INDUSTRIAL USES

Research on chemical agents to protect industrial materials or increase radiation effects in them has lagged behind research on biological protection.

Some of the most active industrial investigations of chemical protection have been on lubricants for nuclear-powered equipment. The lubricating quality of mineral oils is protected by admixing aromatic compounds such as 1-methylnaphthalene (*62*) or phenyl-α-naphthylamine (*63*). Synthetic oils are protected by adding antioxidants and other compounds. The beneficial effect is not simply removal of dissolved oxygen. Some conventional oxidation inhibitors actually accelerate radiation damage, while free-radical scavengers, not particularly known for their antioxidant activity, are protective (*62*).

Chemical incorporation of aromatic ring systems into oil is another way of protecting its properties; this avoids volatility problems. Alkyl-aromatic oils combine the high viscosity of alkyl chains with the energy-dissipative properties of aromatic rings (*62*). Polyphenyl ethers form another radiation-resistant class of oils that have the protective effect of aromatic rings (*64, 65*).

Soaps, conventionally used in the gelation of greases, are particularly susceptible to radiation. Aromatic compounds such as the terephthalamates (*66*) provide radiation-resistant gelling agents, and greases based on the Indanthrene dyestuffs (*67*) are also useful in a radiation field.

Improvement in the properties of fluids such as reactor coolants should also be possible with chemical protective agents. As an example, the radiation resistance of *m*-terphenyl was increased 30% by the addition of only 4% *p*-terphenyl (*68*).

Elastomers and Plastics

Many additives protect rubber during irradiation. While many of the usual antioxidants offer protection, the order of effectiveness is not closely related to antioxidant activity in rubber in the absence of radiation (*69*). Again mechanisms other than oxygen scavenging are suggested. Compounds at molar concentrations equivalent to 2% hydroquinone were found to inhibit up to 75% of the radiation crosslinking of rubber (*70*). In this case, protection was correlated with ability to scavenge free radicals.

A variety of compounds noted for radical scavenging inhibit radiation-induced crosslinking of polyethylene (*71*) and polystyrene (*72*), and crosslinking of butadiene is prevented by copolymerization with styrene (*73*). Inhibition of chain scission by chemical additives is important in industrial as well as biological applications (*18, 22, 26*).

Radionuclide labeling of the additive can be valuable for determining its action. For example, the apparent decrease in main-chain scissions of polymethylmethacrylate in the presence of naphthalene might be owing to either the protective effect of naphthalene or its use as a restorative link between broken chains. The absence of radioactivity in the irradiated main chains when C^{14}-labeled naphthalene is used eliminates the possibility that the action is restorative (*74*).

Glass

Glass darkening has been ascribed to two processes: oxidation of cationic impurities and ejection of electrons into defect holes in the glass structure (*75*). Both processes increase light absorption. It has been known for some time that addition of ceric oxide to glass minimizes darkening during exposure to ultraviolet (*76*), and the same technique has been used to protect the transparency of irradiated glass. Presumably the protective mechanism is scavenging of ejected electrons by ceric ions, which are reduced to colorless cerous ions (*77*).

Sterilization

Chemical protection would also be profitable in sterilization of food and medicinal products. Various additives have been used to modify undesirable effects resulting from protein decomposition in meat (*78, 79*). Addition of acetic acid or tomato products proves especially beneficial in protecting beef from off-odor and -flavor development (*80*). Decomposition of fat in irradiated meat is inhibited by addition of citric acid or deposition of various phenolic compounds (*81*).

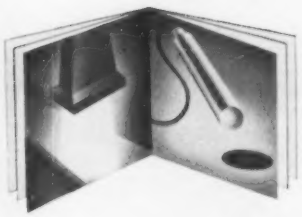
Interesting examples of protective action are also observable in radiation effects on food color (*82*). The red pigment astaxanthin in shrimp is bound to a protein and is more resistant to bleaching than the same compound in salmon, in which it is dissolved in unsaturated lipid. In strawberries bleaching of the anthrocyanin pigment is prevented by adding ascorbic acid.

Protective agents may also prove valuable in radiation sterilization of textiles. Wool, sterilized by radiation after treatment with fluorinated dinitrobenzenes or quinone, deteriorated much less than untreated material (*83, 84*).

Ion-Exchange Resins

Chemical protection of ion-exchange resins would be of considerable value during separation of radioisotopes at concentrations that result in radiation damage to the resin. Substituents on the polymer chain may be found to serve this purpose since the resin structure apart from the ion-exchange sites appears quite important.

One sulfonated polystyrene resin loses 15–35% of its exchange capacity per watt-hour of gamma radiation, while a sulfonated phenol formaldehyde resin loses only 1% (*85*). Protective agents such as AET, α-chloralose and cysteine added to solutions in contact with sulfonated phenol formaldehyde resins prevent an increase in the acidity index of the resin (*86*). It appears that hydroxyl radicals modify the properties of the resin by substitution and that the protective agents act as radical scavengers. (*Continued on page 130*)



APPLIED RADIATION CASE HISTORY NO. 4

Tracer Follows

Normal electrodeposition accentuates roughness by putting more metal on peaks than in valleys. A tracer shows how some additives reverse the effect to make smooth deposits

By SEWARD E. BEACOM and BERNARD J. RILEY
General Motors Research Laboratories, Warren, Michigan

IN ELECTROPLATING one usually wants to produce a smooth and shiny surface. This requires a reversal of some of nature's laws; normal electrodeposition accentuates roughness by putting more of the plating onto the peaks than into the valleys of a plated surface. Current density is greatest at the peaks because electric field strength is greatest there. Making a smooth and shiny surface requires that more metal go into the valleys than onto the peaks, the opposite of the normal effect. Addition of certain organic compounds to a plating bath produces this leveling (*1*). Our problem is to discover why.

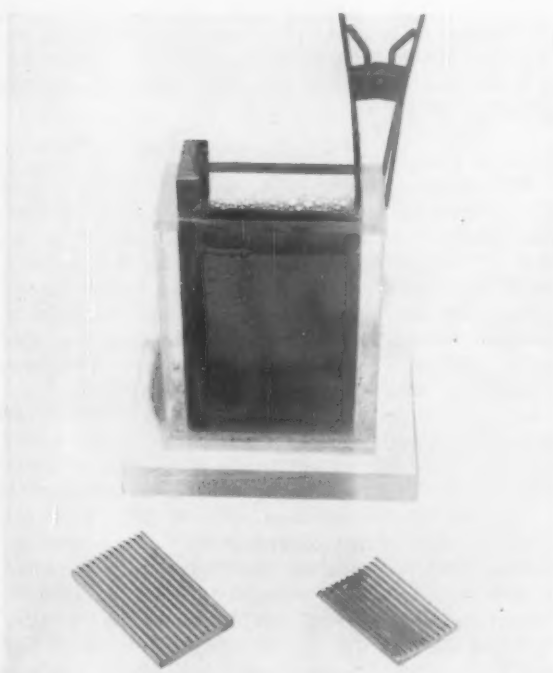


FIG. 1. PLATING BATH, BRASS CATHODE AND FOIL used to show that certain organic agents are deposited preferentially on peaks, diverting metal into valleys to produce level plating

To find the answer we have labeled one leveling agent, sodium allyl sulfonate (*2*), with S^{35} (167-kev betas, 87-day half-life). With this in the plating bath we have deposited nickel foils on especially made brass cathodes. Radioautographs and counting data from the nickel foils show that molecules of the addition agent (or their reduction products) are preferentially deposited on the peaks. This offers confirmation of a theory that partially accounts for leveling.

Leveling Action

Why do certain organic compounds reverse the expected deposition of more metal on large-current-density areas? Some theories assume that the agent is preferentially adsorbed onto the high points of an irregular surface where it acts as an insulator (*2–6*). This inhibits deposition of metal and diverts current to recessed areas. Confirmation of the theory requires a technique to show the location of addition agents in leveled deposits.

Our study has two purposes: (a) to determine whether an organic leveling agent is indeed preferentially adsorbed (or codeposited) on peaks and (b) to develop radiotracer techniques for finding the agent in the deposit. The system chosen for study, sodium allyl sulfonate and N-allyl quinaldinium bromide, has been shown to produce bright and level deposits (*7*). We put these organic addition agents into a Watts-type nickel bath, produced electrodeposits and studied them with counting and radioautography.

Tracer Synthesis

Labeled sodium allyl sulfonate was synthesized by the reaction between allyl bromide and S^{35}-labeled sodium sulfite. The final product was dissolved in water to a concentration of 3 mg (20 μc) per milliliter. This specific activity, determined by proportional counting, shows a recovery of ~95% of the original activity. Chemical composition of the product was verified by infrared analysis (*8, 9*).

Plating Procedure

To prepare the plating solution we added 1 ml of the radioactive sodium allyl sulfonate solution and 150–200 mg of inert compound to 100 ml of nickel stock solution. In some experiments, a second organic agent, N-allyl quinaldinium bromide, was added (0.2–0.6 mg per 100 ml of solution).

Leveler in Electroplating Bath

Plating took 100 min at 58°–60° C and current densities of 20–40 amp/ft².

Since we wanted a surface consisting of peaks and recesses, we prepared grooved cathodes from brass blocks measuring 4.4 × 2.5 × 0.32 cm. Grooves 0.08 cm deep with included angles of 90 deg were cut into one face of each block parallel to the long edge; each block had 13 peaks and 12 recesses. So that we could remove foils of the plated metal, we first plated the brass cathodes with a thin deposit of nickel from a sulfamate bath and then passivated the surface by 1-min immersion in a 0.5% potassium dichromate solution. Figure 1 shows the plating cell, a grooved brass cathode and one of the foils.

At the conclusion of plating, the cathode was withdrawn from the cell and rinsed with distilled water; then a scalpel was used to remove the foil from the cathode block. We scrubbed the foil on both top and bottom to remove any adhering material, rinsed it with water and alcohol and then dried it under an infrared lamp for counting and radioautography. We made 65 plating experiments and 55 nickel foils.

Counting

Counting of plated cathodes and foils removed from them was carried out in a proportional flow counter. This provided a gross count of the activity on top and bottom of each foil but gave no information about distribution of the activity. The data were useful in computing radiographic exposures.

For quantitative distribution data we made a slotted lead counting shield that enabled counting only the activity at a peak or that in a valley. A 0.01-cm-thick piece of lead foil was corrugated to duplicate the surface of the nickel foils by pressing it into the grooves of one of the cathodes. In the center of one peak we cut a single slit 0.005 cm wide and 2.5 cm long.

All peaks on a foil were counted individually; by inverting the lead foil we could fit the slit into a valley and count each valley individually. Continuing in this way we made a profile of the peak and valley counts for both sides of a foil. (We use "peak" to represent that portion of a foil opposite a peak of the cathode, even though that portion looks like a valley when one looks at the bottom of a foil.) Figure 2 shows how the counting shield fits over a foil.

Results of this counting method are shown in the table. The size of the foil from which these data were obtained was ~3 × 4 cm, and the foil showed a gross count on each side of ~10,000 cpm. These results show that more activity is deposited on the peaks than in the recesses.

Radioautography

Our primary source of information on distribution of radioactivity over a foil is radioautography. Since S^{35} emits only a very weak beta particle, we thought at first that it was

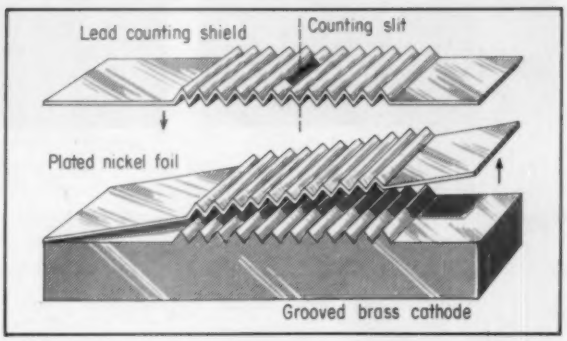


FIG. 2. CATHODE, FOIL AND SHIELD. Grooved brass cathodes were plated with nickel. Passivated surface permitted stripping foil. Counting shield had groove that limited betas activating counter to those from one peak or one valley

Lead-Slit Counting Rates*

Foil A—Top†		*Foil B—Top*	
Peak	*Recess*	*Peak*	*Recess*
125	94	42	27
115	72	33	33
115	53	76	53
143	63	47	81
213	80	177	91
226	163	163	160
224	212	94	97
125	65	147	34
106	64	43	28
55	55	59	45
79	57	58	
Foil A—Bottom		*Foil B—Bottom*	
Obverse of peak	*Obverse of recess*	*Obverse of peak*	*Obverse of recess*
248	143	145	58
198	103	133	77
152	133	134	84
120	112	154	65
207	102	135	100
254	113	190	128
227	163	212	126
150	146	176	101
146	129	163	82
181	158	144	80
242	129	102	

* Counting was left to right on the top of the foil and right to left on the bottom, so that the values in the columns are matched.
† "Top" refers to the side next to the solution during plating, "bottom" to the side next to the cathode.

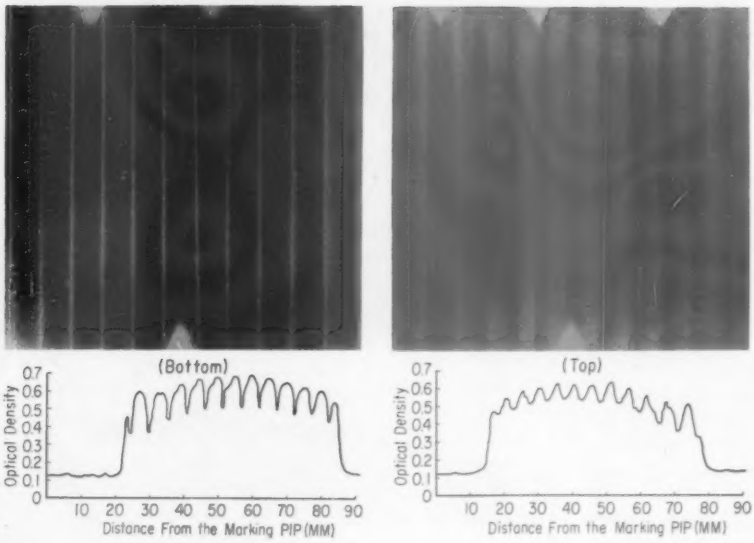


FIG. 3. RADIOAUTOGRAPHS and density traces from them show how leveling occurs. Organic deposits on peaks (dark), and unevenness becomes progressively less from bottom to top as leveling action proceeds. Explanation is that organic serves as insulator and diverts plating current into valleys

necessary to have the foil in direct contact with the film. Therefore most of the foils were mechanically flattened, placed between two pieces of film and weighted to ensure good contact. (Later tests with a foil before and after flattening show that flattening produces no advantages for either radioautography or counting.)

To ensure that everything on the final radioautograph was caused by radioactivity and not side effects, we exposed foils containing no radioactivity under identical conditions. These tests showed no side effects caused by chemistry or pressure. Several types of film were used; radioautographs shown here were made on Eastman Kodak Type AA film.

Data

Figure 3 is a set of representative radioautographs of top and bottom surfaces. These reproductions are positives, identical with the original radioautographs. Darker areas indicate regions that contain more radioactivity. Since we must make an intermediate negative to achieve this reproduction, some detail has been sacrificed. Notches and holes in the foils visible in the radioautographs were cut to identify peak areas. This system of notching not only enables identification of the individual foils but also precisely locates peaks and valleys.

Readings of the radioautographs have been made with a Leeds and Northrup Linear Recording Densitometer and a General Motors Research Laboratories light source and scanning device. Results are recorded below each of the radioautographs of Fig. 3. A slit width of 0.127 mm was used; slits narrower than this did not contribute to detail but led to increased instrumental fluctuations. Because this system records a marking pip at each 0.5 mm, it is possible, by placing a mark near the edge of the radioautograph, to measure distances from the edge accurately. Before use the instrument was calibrated with a standard step wedge. Thus recorded densities are actual densities from exposure to radioactivity. All possible variables in film processing are kept constant.

Results

Radioautographs like those of Fig. 3, density traces made from them and slit counting data like the table all show that there is greater deposit of radioactivity at the cathode peaks than in the valleys. Two effects contribute to the data: first, there is more radioactivity (sodium allyl sulfonate or a reduction product containing S^{35}) at the peaks and less in the valleys; second, there is more metal in the valleys to absorb the soft S^{35} beta particles than on the peaks.

The data also show that there is greater smearing of activity on the tops of the foils than on the bottoms. We interpret this smearing as showing that plating produces leveling, and as leveling proceeds, the difference between peak and valley plating rates becomes smaller.

To initiate leveling, the addition agent first must be concentrated preferentially on the peaks. Our data as well as those recorded in the literature confirm this assumption. The mechanism of this concentrating action has not yet been demonstrated satisfactorily. There is some evidence that the sulfide ion, a reduction product of sodium allyl sulfonate, is present in the electrodeposited nickel (*7, 10*). In the present work no attempt was made to distinguish between the possible presence of the sulfonate or the sulfide.

A tracer problem for the future is to find out how the S^{35} is preferentially deposited on the peaks.

* * *

The authors are grateful for the assistance provided by several members of the General Motors Research Laboratories staff who carried out analytical and photographic procedures.

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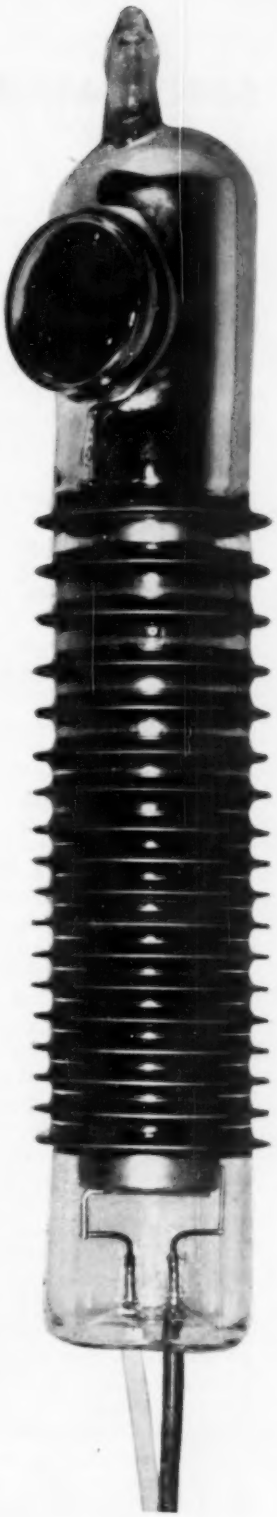
SCINTILLATORS AND SEMICONDUCTORS



Continuing a tradition that now extends over more than a decade, members of the scintillation-counter fraternity gathered in Washington on February 25 and 26 for the Seventh Scintillation Counter Symposium. Continuing its own tradition of reporting the highlights of these symposia, NUCLEONICS here presents a 16-page report on the present status of the field. The title—Scintillators and Semiconductors—reflects the fact that this is no longer a meeting given solely to devices whose detecting action involves minute flashes of light. The burgeoning field of semiconductor-junction detectors needed a forum for discussion and the symposium management wisely provided it. It is clear that this will be equally necessary at the next symposium, probably in 1962.

It seems to us that scintillation counters have attained a certain maturity. At least by comparison with semiconductor detectors (or the early days of scintillation counting itself) there is not the same rush of developments. This is not to say that there is not important progress: Scintillation track imaging, the subject of a complete session at the Symposium, has brought us to the point where rudimentary tracks of minimum-ionizing particles can be "seen." Our understanding of the scintillation process, particularly in organic materials, has been refined. No similar advance has obtained in the theory of inorganic scintillators, however—no one has solved the puzzle of why the resolution of NaI crystals isn't as good as light-pulser measurements would promise. The alchemists who make scintillators are doing better than the theorists and explainers—glass scintillators and CsI scintillators are new themes at this symposium. While there were no big surprises in photomultipliers, the usual interest attended manufacturers' accounts of latest refinements in their products; particular interest was shown in high-temperature design and transmission-type image amplifiers. We've tried to reflect that which seemed most important.

Reprints of this report are available from our reprint department at 75¢ each. The complete proceedings will be published in the *Transactions of the Professional Group on Nuclear Science of the IRE.*

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SCINTILLATION THEORY

Today's models of the scintillation process accurately explain small efficiency, crystal response as a function of stopping power, slow and fast components of pulses from organics

How HIGH-ENERGY photons and particles affect scintillators is now understood with remarkable precision. Several papers at the Scintillation Counter Symposium offered detailed explanations of the complex processes that occur between the entrance of a particle into a detector and the release of the last electron from the photomultiplier cathode some 10 μsec later. For scintillating crystals one can derive a theoretical curve for pulse height as a function of particle energy and achieve an impressive fit to available experimental points. For organics one can have convincing, but not entirely unique, explanations of the fast and slow pulse components that are useful for particle identification.

Crystal Scintillation

Computations by **A. Meyer** and **R. B. Murray** of Oak Ridge derive responses of activated alkali-halide crystals with accurate enough detail to offer impressive confirmation of the assumed model (*1*). According to the model a scintillation consists of (a) slowing of a charged particle by formation of hole-electron pairs, (b) recombination of pairs into excitons, (c) diffusion of the excitons to activator sites and excitation of activators, (d) radiative decay of excited activators. Computations based on these assumptions derive the theoretical curve of Fig. 1.

The figure shows scintillation efficiency of cesium iodide as a function of stopping power, dE/dx. (Scintillation efficiency is defined as dL/dE, the ratio of differential light output to differential energy loss. In other words it is the slope of a curve that shows light output as a function of total energy loss.) Meyer and Murray have normalized data of several investigators for electrons, protons, alpha particles, heavy ions and fission fragments to show how efficiency is greatest for protons and less for both lighter and heavier particles. Their computations show why these things are true.

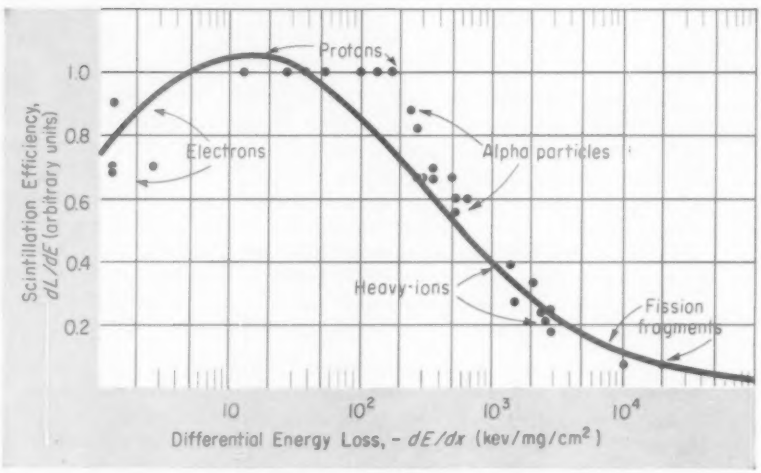

FIG. 1. SCINTILLATION THEORY PREDICTS EFFICIENCY in good agreement with normalized data from several measurements. Model assumes creation of hole-electron pairs, recombination into "excitons" and migration to solute sites

Equations that lead to the curve describe formation of hole-electron pairs, formation of excitons by recombination, diffusion of excitons and exhaustion of unexcited (available) activator sites as follows:

$$n_e = K(-dE/dx)$$

$$n_0 = \frac{\alpha n_e^2}{1 + \alpha n_e}$$

$$\frac{\partial n}{\partial t} = D\nabla^2 n - nv(N_1\sigma_1 + N_a\sigma_a)$$

$$\frac{\partial N_a}{\partial t} = -nvN_a\sigma_a$$

(n_e = linear density of hole-electron pairs; K = empirical constant determined by best fit; n = volume density of excitons; n_0 = initial value of n; α = recombination parameter; D = diffusion constant; v = exciton velocity; N_1 = density of lattice sites; σ_1 = cross section for exciton capture at a lattice site; N_a, σ_a = density and cross section of activator sites.)

The last equation deals with the situation in which n is large and N_a small so that saturation occurs and most or all activator sites have accepted excitons and cannot accept more. In contrast the number of lattice sites N_1 (which includes *all* trapping mechanisms) is so large as to be considered constant.

Treatment of the equations consists in solving for n_0, considering it subsequently as a delta function in space, assuming an initial value of N_a (0.1 mole %) and then solving in cylindrical symmetry. The result is the curve of Fig. 1, which rises at small energies because n_0 is proportional to n_e^2, reaches a maximum as n_e increases and n_0 becomes proportional to n_e, and then turns downward at still greater energies as activator sites become saturated.

Meyer and Murray have used their curve to predict pulse heights as functions of energy for different particles and get results (subject to one normalization) in good agreement with experiment. Their normalization makes the diffusion length for the excitons ~30 A.

Organic Scintillation

Students of scintillations in organics have come to an understanding of both sizes and shapes of scintillation pulses.

Their theories differ in a few details and offer areas for future study. But they are mainly in agreement as to what goes on in time and space. Summaries of present theories were presented at the conference by both **J. B. Birks** (*2*) of the University of Manchester and **Warren L. Buck** (*3*) of Argonne.

Theorists must explain (a) the relative inefficiency of the conversion of particle energy into light as compared with optically excited fluorescence, (b) the fast portion of the scintillation pulse with a decay time of $\sim 10^{-7}$ sec, and (c) the slow portion with a decay time of $\sim 10^{-3}$ sec. Inefficiency can be explained in terms of large-energy transfers that lead to molecular destruction, heat and other non-light-producing modes of energy flow. Fast pulse components probably come from singlet excited states of solvent and solute that return rapidly to the ground state by allowed light-producing transitions. Slow components probably come from triplet states formed mainly by ion recombination and decaying slowly by forbidden transitions.

Migration theories have also been suggested to explain pulse shapes. They assume that initially there is rapid quenching and fluorescence along a particle track and that this is followed by migration of particles away from the track, subsequent recombination and slow fluorescence. These theories fail to explain why decay times remain unchanged as one changes the manner of excitation.

The Birks and Buck papers were substantially in agreement as to their preferred theories of the process. Initially a particle that is stopped in a scintillator contributes about half of its energy to excitation, which increases electronic energies without disrupting molecules, and the other half to ionizations, which disrupt molecules by removing electrons and fracturing bonds. Since the solute is in small concentration, most of this stopping energy goes initially to solvent molecules but then goes rapidly to solute molecules.

Energy flow in the early stages of a scintillation ($\sim 10^{-10}$ sec) is shown in Fig. 2, an adaptation of one of Birks's slides. Ionizing radiation produces free electrons and ionized molecules (ionization) and excited molecules (excitation). Free electrons (a) perform as degraded radiation, (b) fall into electron traps to produce quenchers, and (c) recombine with ionized molecules still capable of producing fluorescence. Ionized molecules combine with each other and free electrons. If the product of the combination is in a sigma state (projection of electron angular momentum on molecular axis zero), it usually is lost to the fluorescence process; it eventually contributes to the population of damaged molecules that serve as quenchers, and its energy is degraded to heat. When the product is in a pi state (projection = 1) the energy usually goes into fluorescence. Statistics say that 25% of such combinations produce singlet states with the spins of the odd electrons antiparallel; 75% produce triplet states with spins parallel. These triplet states appear to be responsible for the slow component of the scintillation. Excitation, too, can lead to sigma states if excitation energy is great enough.

According to this view of the situation, pulse-shape discrimination among different kinds of particles results from different apportionments of energy between ionization and excitation: protons produce one apportionment, alpha particles another, and so on.

Other theories have their supporters, however, as demonstrated in Buck's paper. One logical assumption is that all the light in a scintillation pulse comes from directly excited molecules and none from ionization. Computation shows that the energies of light and excitation are about equal.

Alternatively one can assume that only the light in the fast component comes from excitation. The slow component, then, would result from the recombinations of positive ions that lead to singlet states—one-fourth of all recombinations. If one assumes equal energies in ionization and excitation, the number of positive ions will be half the number of directly excited molecules; one fourth of this half will produce singlet excited molecules; so one eighth of all singlet excitation will come from recombination. This is roughly equal to the fraction of the light Owen finds in the slow components of his pulses (NU, Sept. '59, p. 92). Recent observations of phosphorescence that lasts for a few seconds after high-energy irradiation may account for the triplet-state excitations; perhaps triplet solvent molecules are taking this long to transfer energy to the solute.

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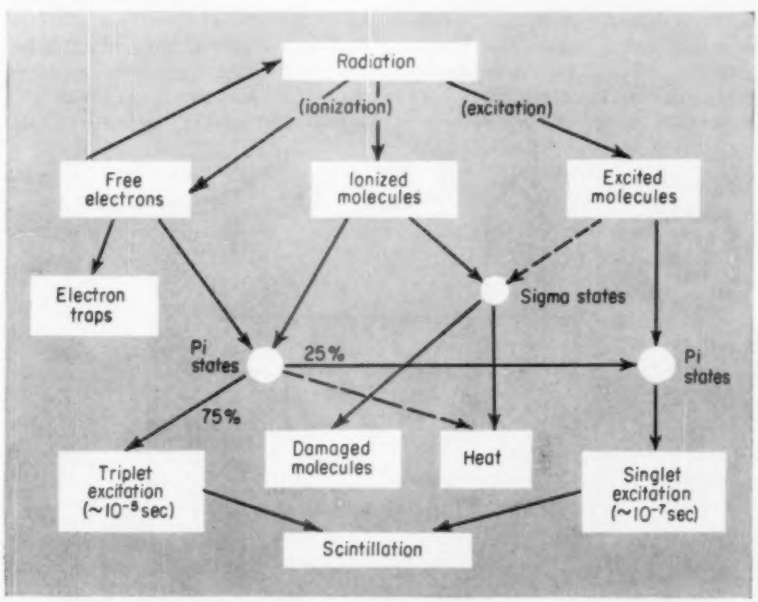

FIG. 2. ENERGY-FLOW PATTERN IN SCINTILLATION may explain inefficiency (much energy goes to non-light-producing processes) and pulse-shape change with type of excitation (more or less of light goes into slow component)

NEW SCINTILLATORS

Improved glasses have small but usable pulse heights and neutron responses. Gases, too, can contain neutron-sensitive nuclides. CsI has advantages over NaI, but it is expensive

THE BEST AVAILABLE scintillators are far from perfect. Much effort is going toward substitutes that will be more efficient, produce better resolution, provide tailored responses and avoid deterioration. Symposium papers described glasses, gases and cesium iodide crystals.

Scintillator Glasses

A bright future may be ahead for cerium-activated glass scintillators judging by the paper of **Robert Ginther** of the Naval Research Laboratory (*1*). For one thing they may solve two of the great problems that darken hopes for filamentary chambers: crazing of plastic filaments and cross talk between adjacent ones.

The main difficulty with scintillating glasses is poor efficiency. The best glass to date from NRL kitchens (a lithium-magnesium-aluminum silicate) produces pulses 14% as high as NaI-(Tl). This is nearly three times as good as what was available two years ago; the makers look for better yet.

Low efficiency, they feel, comes from an unexplained equilibrium between ceric and cerous ions. The result is ceric absorption of the cerous emission that makes up the scintillation. The hope is to upset the equilibrium in favor of the cerous ion. Meanwhile it may be possible to bring about an improvement in energy transfer from base glass to emitting centers; scientists are convinced that the transfer occurs.

Recipes that lead to useful glasses and the pulse heights that come from them are listed in Table 1. These are representative samples from many combinations and permutations that have been compared in the effort to find useful glasses with efficient responses. Lithium and boron contents make them sensitive to neutrons.

Glasses 1 and 2 are earlier NRL glasses, and 3 and 4 are NRL copies of Russian glasses (V. K. Voitovetskii et al., *Atomnaya Energiya* **6**, 321, 1959). Glass 5 is the result of an effort to incorporate a maximum of boron and retain usable pulse height. Its Ce_2O_3 concentration is optimal for pulse height. More than 65 mole % and less than 45 mole % of B_2O_3 make unclear glasses. More than 25 mole % of Al_2O_3 makes unclear glasses; too little makes clear but inefficient glasses.

Glass 6 is based on a formula that for clear glasses requires $\frac{Mg + Ca}{Si} = 1$. Lithium, aluminum and cerium are substituted for calcium, which reduces pulse height, so that the formula becomes $\frac{Mg + Li + Al + Ce}{Si} = 1$. This ratio can vary from 0.82 to ~1.2 in clear glasses with nearly constant pulse height.

TABLE 1—Compositions of Scintillating Glasses

Glass	Composition (molar proportions)						Pulse height [% of NaI(Tl)]
	Na_2O	MgO	Al_2O_3	B_2O_3	SiO_2	Ce_2O_3	
1	1.0	—	1.33	3.0	—	0.10	5.0
2	1.0 Li_2O	—	1.33	1.0	1.5	0.10	7.0
3	1.0	—	—	—	2.0	0.005	1.5
4	1.0	—	0.08	—	3.0	0.0075	3.0
5	—	0.625	1.125	3.25	—	0.10	5.0
6	0.065	0.26	0.05	—	0.50	0.005	14.0
7	0.165	0.06	0.05	—	0.50	0.005	10.0
8	0.1825	—	0.0375	—	0.55	0.005	9.0

Gas Scintillators

Neutron detectors with sharp thresholds, large sensitivities and large resolutions are growing out of the work of **Charles Engelke** at Columbia with gas scintillators (*2*). Among their advantages are good gamma-background rejection, larger counting rates than from a long counter of the same efficiency, smaller gas requirements than those of low-pressure proportional

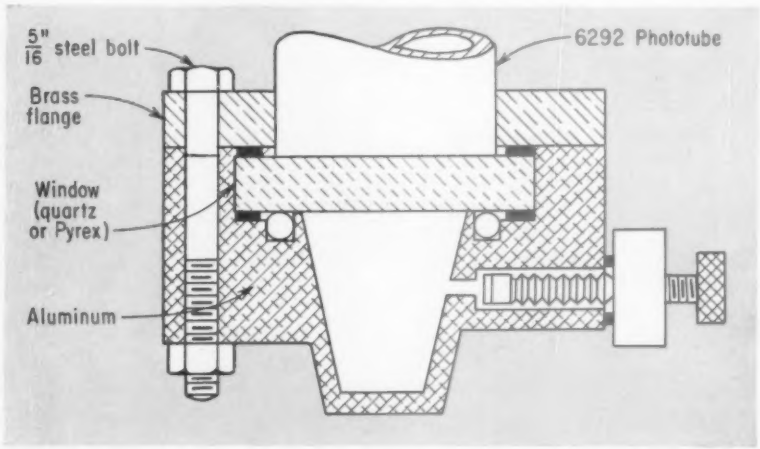

FIG. 1. GAS SCINTILLATION DETECTOR FOR NEUTRONS has good background rejection, short decay times, useful counting rates and good efficiency

counters in measuring n,α and n,p cross sections of rare nuclides and short decay times for time-of-flight measurements.

Engelke's counter (Fig. 1) is a tapered aluminum chamber, ~1.5 in. in diameter at the top, covered by a glass window and coupled to a photomultiplier. A wavelength shifter, usually diphenyl stilbene, coats walls and window. Xenon or argon goes in as a scintillator to pressures up to 75 atmospheres and then a few per cent of nitrogen or neon to provide N^{14} or Ne^{20} neutron resonances.

Nitrogen appears to poison the counter at large pressures by forming four-atom molecules and shifting emission energy into the infrared. Nevertheless with small enough concentrations one can make a threshold detector with 29.5% resolution for 0.495-Mev neutrons on 400-psi xenon and 100-psi nitrogen.

For broader sensitivity Engelke fills the chamber with a helium-xenon mixture to make a counter usable from 0.1 to 50 Mev with efficiencies as great as 20%.

CsI(Tl) for NaI(Tl)

Experiments are showing that newly developed CsI(Tl) crystals are in many ways better scintillation detectors than NaI(Tl) according to **Charles Schmidt** of Harshaw Chemical Co. (*3*). Since CsI has greater stopping power than NaI, the user can get the same response from smaller and lighter detectors or a better response with crystals and shielding of the same size. Another advantage that appeared in audience discussion of the paper is a smaller inclusion of radioactive potassium. Present techniques permit manufacturers to reduce the potassium inclusion to 1–3 ppm of the natural element (0.012% of which is K^{40}). For low-level counting radioactive K^{40} in a NaI crystal may set the background limit; in CsI it should be possible to reduce potassium content to zero.

Disadvantages of CsI in comparison with its better-established rival are smaller light output, much slower light decay and higher cost. The present manufacturer (Harshaw Chemical Co.) indicated in reply to an audience question that CsI is now about three times as expensive as NaI but that this "may be open to negotiation."

Characteristics. Harshaw has been testing a 5-in.-diameter, 3.5-in.-high crystal coupled to a Du Mont 6363 photomultiplier and is presently proceeding with tests of a 5 × 5-in. crystal. A comparison of CsI(Tl) and NaI(Tl) characteristics is given in Table 2. Figure 2 shows Cs^{137} and Co^{60} spectra measured with the smaller Harshaw crystal. Future tests may show considerable improvement from coupling the CsI crystal to more appropriate photomultipliers; there is reason to believe that the S-11 response used with NaI is not the best for CsI.

The root of the advantages of CsI is large photofraction (fraction of recorded events falling in the photopeak and thus representing total absorption in the crystal). Figure 2 is an example: large photopeaks and small Compton continua produce unusual signal-to-background ratios. The 5 × 3.5-in. CsI crystal has considerably better photofractions than a 5 × 4-in. NaI crystal, the ratio being 1.25 at 2.76 Mev.

Tests also show that CsI crystals offer linear response over a range at least as great as 0.08–7.13 Mev. Resolution from the 5 × 3.5-in. crystal has been compared with that of an 8 × 8-in. NaI(Tl) crystal; the two are equal at 7 Mev and nearly equal down to energies of 0.5 Mev. The extrapolated CsI resolution at infinite energy is 2.8%.

TABLE 2—Properties of CsI(Tl) and NaI(Tl)

	CsI(Tl)	*NaI(Tl)*
Relative light output	0.40–0.45*	1
Wavelength, emitted light (A)	4,200–5,700†	Centered at 4,100 A
Decay constant (μsec)	1.2	0.25
Relative linear attenuation coefficients:		
Pair production	1.42	1
Compton	1.47	1
Photoelectric	1.56	1

* Measured with S-11-response phototube and ~15-μsec anode time constant. † Unpublished data of Bonomomi and Rossel quoted by B. Hahn and J. Rossel in *Helv. Phys. Acta* **26** (1953).

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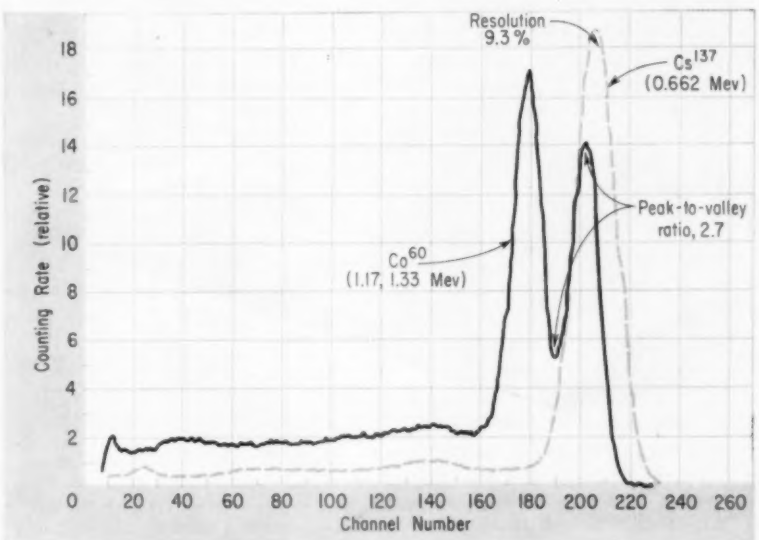


FIG. 2. CsI(Tl) CRYSTAL OFFERS LARGE PHOTOFRACTIONS in Co^{60} and Cs^{137} spectra. (Spectra have different energy and counting-rate scales)

PHOTOMULTIPLIER DEVELOPMENTS

Special-purpose tubes are suitable for boreholes, space flight and intense radiation pulses. Developments are reducing noise, increasing speed and resolution, making responses more uniform

SYMPOSIUM PAPERS on the science and technology of photomultipliers show a broad frontal attack, mainly by commercial manufacturers, on problems that currently limit the usefulness of the tubes: dark currents, noise, rise times, resolution, sharpness of pulses.

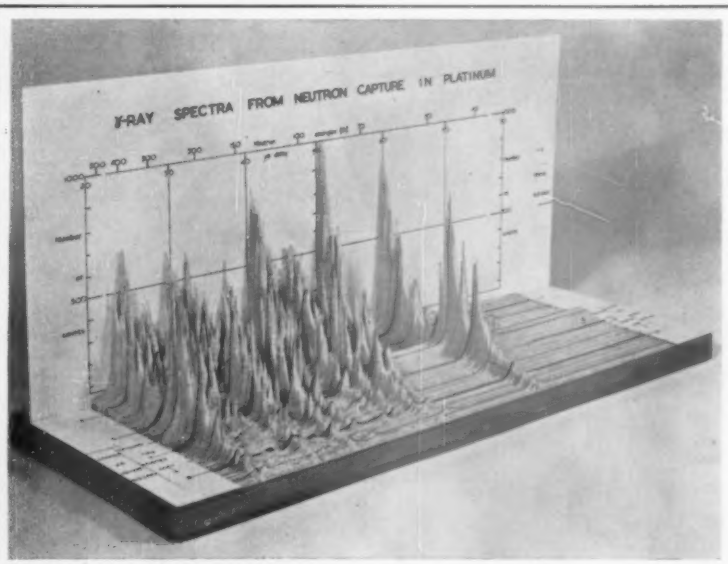
Special Phototubes

While many users are shockmounting their photomultipliers and cooling them to reduce leakages and dark currents, well loggers are dropping them down high-temperature, small-diameter bore holes, and bomb testers are exposing them to momentary flashes of intense gamma radiation. Developments for these purposes have produced photomultipliers capable of good signal-to-noise ratios at 150°–200° F and single-stage phototubes linear to 55 amp.

For high temperatures Schlumberger Well Surveying Corp. has developed a series of tubes described at the symposium by **J. P. Causse** (*1*). By eliminating cesium the makers avoid electrical leaks at the sacrifice of sensitivity and resolution. To regain sensitivity, they use special constructions that permit higher-than-usual interdynode potentials.

Tube envelopes are made of alternating metal and hard-glass rings like the accelerating tubes of electron-beam generators (see cover). Venetian-blind silver-magnesium dynodes are mounted on the glass rings, and resistors of the potential divider are mounted between adjacent pairs of them. This construction permits operation at overall potential differences as great as 4,000 volts. A 14-stage tube offers a multiplication of 10^7 at 4,000 volts, output sensitivity of 200 amp/lumen and a signal-to-noise ratio at room temperature ~100 times as good as those of conventional cesium-antimony photomultipliers. Without damage the tube will sustain 50-*g*, 11-msec shocks and 20-*g* vibrations at 3,000 cps.

Combinations of the high-temperature dynode structure and conventional cathodes produce rugged low-noise photomultipliers. The makers achieve usable gains of 5×10^7 with 14 stages and 2×10^8 with 18.



MULTIDIMENSIONAL DATA FROM YARDS OF MAGNETIC-TAPE show neutron resonances and their gamma energies. Accumulation required 255 time-of-flight channels (¼-μsec each), 63 energy channels (4 × 4-in. NaI counter), 100 hr of experiment time (instead of usual 4–6 months), and ~35 hr of analysis. Harwell system was described by J. R. Bird, J. R. Waters, F. H. Wells (7)

Testing Programs

For better photomultiplier performance all of the commercial manufacturers are instituting experimental and production-line tests, described in papers by **J. Sharpe** (EMI), **R. W. Engstrom, R. M. Matheson** (RCA), **Sydney Roth** (DuMont), **R. B. Linden, F. W. Schenkel** and **P. A. Snell** (CBS) (*3–6*). Principal subjects of the tests are cathode uniformity, transit-time spread, signal-to-noise ratio, pulse-height resolution and pulse-height shift with counting rate.

For transit-time spread DuMont compares outputs from two similar tubes pulsed by a split light beam from a mercury source (0.5-mμsec rise). By moving a mirror one can excite different points on the cathode of the sample tube, and by changing path length for one of the beams, one can change the delay between the two.

Noise, resolution. Production-line tests at EMI and RCA use pulsed scintillators to measure signal-to-noise ratio and pulse-height resolution. At EMI the goal is sensitive tubes for tritium counting; candidate tubes are exposed to a tritium-loaded sealed liquid scintillator at room temperature. Currently 15–20% of EMI 6097F's give backgrounds of 5 cps or better with a counting rate of 90 cps.

RCA has developed a test for resolution that will be standard procedure when one of its developmental tubes (C-7260) goes into production in a few months. Each tube is exposed to a Cs^{137}-excited NaI(Tl) crystal; worst acceptable resolution has been set tentatively at 9%.

Pulse-height shift. CBS has been concentrating on why pulse heights often shift with counting rate. Its engineers have made a double-ended tube, one end containing an electron gun with a beam focused into the multiplier structure. They are surprised to find that for 25-μamp pulses and cath-

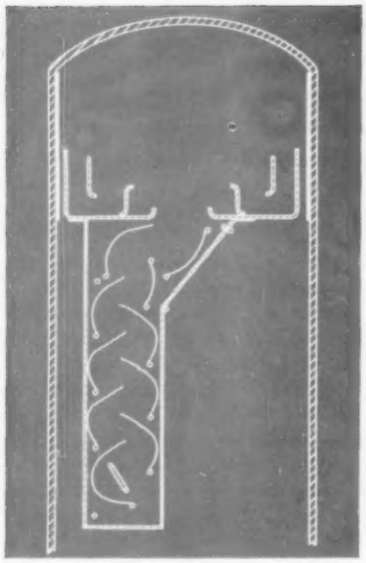


FIG. 1. FOR FAST RESPONSE this structure presents large first-dynode area for collection from photocathode

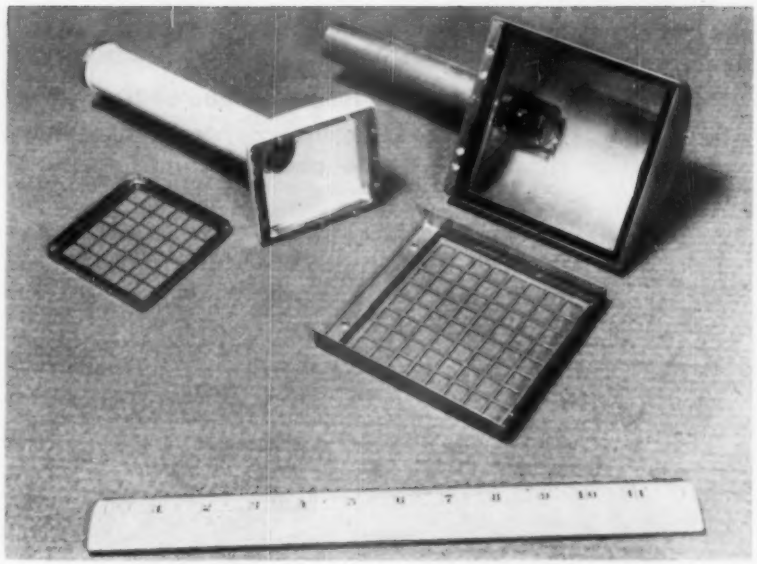


FIG. 2. COMPACT BENCH-TOP MONITOR (upper right) uses special photomultiplier with cathode on side walls as well as end window. Cathode area is five times as great as 4-cm² end window and resulting monitor is only 2½ in. deep

odes of silver magnesium, aluminum oxide and copper beryllium, the most stable tubes are those that have been aged (1 ma, ½–2 hr) after addition of cesium.

Phototube Improvements

Off-the-shelf photomultipliers from the shops of the several commercial manufacturers include many recent improvements; many more are on drawing boards and moving toward the workbenches (*3–6*). Users can look for smaller transit-time dispersions, shorter rise times, tubes with and without side-wall sensitivities (user's choice), ruggeder internal structures, noise-free cathodes and low-radioactivity tubes.

Transit and rise times. At least three manufacturers, CBS, RCA and EMI are developing special cathode and dynode structures to make sharp, short pulses. The RCA C-7260 has a structure (Fig. 1) intended to meet the dilemma of presenting a maximum first-dynode area to electrons from the cathode and also providing optimal acceleration of secondaries along the axis. Dynodes 2 and 3 are especially designed to turn the corner into the recurrent structure that follows. The new structure provides shorter inter-dynode transit time and thus reduces transit-time dispersion.

CBS also has a quick-rise, small-dispersion structure. Its tube has an over-all 2–3-mμsec rise and a 1-mμsec rise in the multiplier itself. A special plano-concave face plate enables use of a curved cathode and special focusing electrode for good coupling to flat scintillators, uniform response across the faceplate and small transit-time differences from various parts of the cathode.

The EMI approach is similar. The initial energies of photoelectrons and the field at the cathode, says EMI, are mainly responsible for transit-time differences. Thus a special, curved, low-interception grid operated at the first-dynode potential has been designed for insertion in EMI tubes. The designers look for an inherent rise time of ½ mμsec. The accelerating-grid design follows experimental work at Harwell showing that the 2.5-mμsec rise in a special fast tube (EMI 9593) can be shortened to 1.7 mμsec by adjusting dynode potentials and in particular, providing an especially large potential rise from cathode to first dynode.

Side walls and noise. For the purposes of a compact bench-top monitor EMI has made a 1⅝-in. photomultiplier with 20 cm² of photocathode (Fig. 2). The large photosensitive area comes from making it extend down the sides of the tube as well as across the face.

Meanwhile CBS finds that when you are taking your signal from the face of the tube, any stray cesium that has got onto the walls contributes many undesirable thermionic electrons to tube noise. CBS prevents any wall deposit by sliding a metal shield into place before the two evaporation processes (antimony, then cesium). Afterward the shield slides back and locks in a position from which its thermionic electrons cannot get into the dynode structure.

For further noise elimination CBS has a design intended to eliminate radioactive materials (mainly in glass) from the photomultiplier. The projected tube would have a sapphire faceplate, nickel-iron neck, stainless-steel body and base, and ceramic insulators for leads. A quartz face would be desirable, but no one yet knows how to seal it to metal. Experimental sapphire-metal seals are already available.

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Recording Particle Tracks with the Luminescent Chamber

Time resolution of 10^{-6} sec, space resolution of 1 mm and image intensifier systems make today's luminescent chambers suitable for recording tracks of minimum-ionizing particles

By MARTIN L. PERL and LAWRENCE W. JONES, *The University of Michigan, Ann Arbor, Michigan*

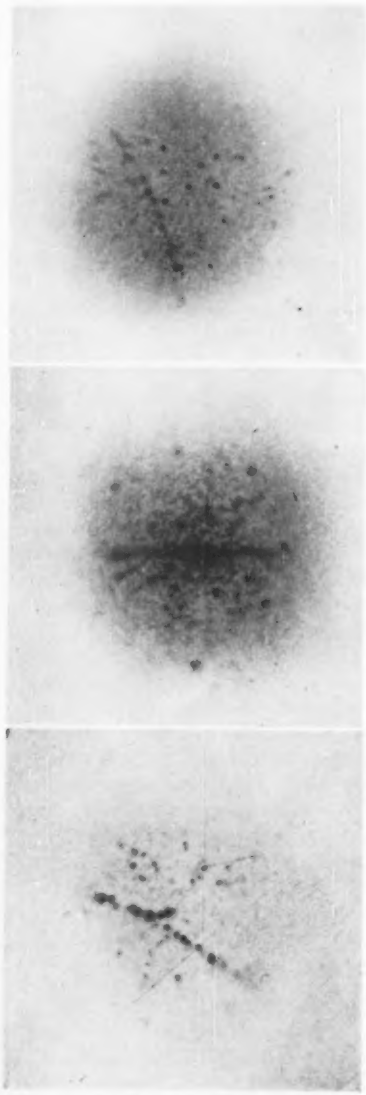

FIG. 1. COSMIC-RAY TRACKS taken in homogeneous NaI(Tl) chamber 2.5 in. deep and 3 in. in diameter. All tracks were at least 1.5 in. long in chamber. Top track is minimum ionizing particle, probably μ meson; it is narrow because relatively small-aperture lens was used in viewing the chamber. Center track was taken with relatively large-aperture lens; therefore track is broad and very dark. That at bottom is probably a scattered track

WITHIN THE PAST DECADE, luminescent chambers have been developed rapidly as devices for recording the tracks of high-energy particles. Their good time and space resolution and electronic operation make them preferable to other track-recording devices for many applications.

With suitable counting and image-intensifier-tube systems, a luminescent chamber can select particular particles or nuclear events from a dense background and accumulate a large amount of statistics. Figure 1 shows tracks typical of those recorded by a luminescent chamber.

As early as 1913, alpha-particle scattering was studied by detecting scintillations in a fluorescent screen (*1*). However, it was not until 1952 that a luminescent chamber was available to make the first photographs of heavily ionizing particle tracks (*2*). In 1956 photographs of less heavily ionizing particle tracks were made for the first time (*3*), and in 1958, the first minimum-ionizing particle tracks (cosmic-ray mu mesons) (*4*).

This sudden, recent development in luminescent chambers was made possible by the development of the image-intensifier tube. The 10^5 light amplification provided by the image tube permits the light emitted by a scintillator to be recorded photographically. In such a tube, the light image is converted into an electron image on the photocathode, the electron image is accelerated and then converted back to a higher-intensity light image on a phosphor-screen anode. Furthermore, the interposition of the image intensifier tube between the scintillator and the recording system has made the luminescent chamber far more useful by permitting electronic gating of the image with time intervals less than a microsecond.

CHAMBER DESIGN

In the current luminescent-chamber concept, two faces of a rectangular scintillator are viewed separately by 1 or 2 image-tube systems. By recording the two projections of a particle track thus obtained, information about track length and angle can be obtained as with bubble or cloud chambers.

Two scintillator materials are presently receiving the most attention—a homogeneous block of thallium-activated sodium iodide or a scintillator built up of plastic filaments.

Homogeneous Chamber

The track photographs presented in Fig. 1 were obtained in a homogeneous luminescent chamber, that is, a chamber in which a transparent homogeneous block of scintillator is viewed by an optical light-collecting system.

Fundamental to all luminescent chamber design is the amount of light produced by charged particles. Table 2 gives the number of photons N produced per centimeter of track in the chamber for various scintillators and various particle energies. The most difficult tracks to record are those produced by minimum-ionizing particles, and for most purposes the luminescent chamber must be designed and constructed to record them. Therefore these are the basis of the following discussion.

Figure 2 shows a homogeneous chamber with a lens that subtends a solid angle Ω in the scintillator. To collect a large fraction of the light, a low-f-number ("fast") lens is required. But the "faster" the lens is, the more difficult it is to obtain a good focus throughout the thickness or depth of the chamber. This is, of course, the same depth-of-field problem that occurs in all high-speed photography. To illustrate this problem, one can calculate the parameters for several different chambers.

Consider a chamber of depth d with the focal plane at the center, as shown in Fig. 2. Then the maximum circle of confusion will occur at the front and back planes with a radius a related to

Ω approximately by

$$\Omega = a^2/d^2 \qquad (1)$$

Of interest is the number of photons that will be *recorded* per centimeter of track in the scintillator. In the image-intensifying system, the light image falls upon a photocathode where it is converted to a photoelectron image, and it will be assumed that each photoelectron will ultimately be recorded. Present good photocathodes have a photon-to-photoelectron conversion efficiency of only 0.2. Defining p as the number of photoelectrons produced per centimeter of track in the scintillator and neglecting absorption and reflection losses in the collecting system

$$p = \frac{0.2\,a^2}{d^2}\,N \qquad (2)$$

The values of d should be selected for a particular N to give $p \cong 1/2a$, so that the spacing of recorded photons along a track approximately equals the maximum width of the track. A final factor in p is the self-absorption of the fluorescent light in the scintillator. In the plastic the bulk attenuation length is about 65 cm (*5*), and in NaI(Tl) it is probably comparable.

The dimensions of the scintillator volume perpendicular to the optic axis are controlled by a different consideration. The number of resolution elements in cross-sectional area of the chamber (assumed square) is limited by the number of resolution elements, R, in the intensifier system. If a cross-sectional dimension is greater than roughly $a\sqrt{R}$, there will be more loss of resolution due to the cross sectional dimension than due to the depth.

Table 3 lists some representative homogeneous chambers calculated for minimum-ionizing tracks. Thus moderate-size NaI(Tl) chambers with dimensions of 10–20 cm and resolutions of 1–2 mm are feasible. It should be emphasized that the resolution a is a minimum resolution and that p is a minimum value (for minimum ionization). If a track has many photons along its length, then a best line can be drawn through these photons with a precision better than a. For low-energy particles, there may be some use in the thin NaI(Tl) chamber with a resolution of 0.1 mm. Also the feasibility of very large, poor-resolution

Properties and Applications of Luminescent Chambers

The luminescent chamber is compared with other track-recording devices in Table 1. Luminescent-chamber properties can be summarized as follows:

Time resolution. The time resolution depends upon the decay time of the fluorescent light in the scintillator and the shutter time of the image intensifier system. At present, this time resolution is 2–5 $\times$ 10^{-6} sec.

Counter control. The 10^{-6}-sec time resolution provides a time delay during which operation of the image tubes can be controlled. Thus, two counters external to the scintillator could be arranged to turn on the image tubes only when the counters are in anticoincidence, indicating a scattered particle.

Spatial resolution. The spatial resolution with which the particle paths are determined is dependent on the size of the chamber. For homogeneous chambers 10–20 cm thick, the spatial resolution will be about 1 mm. Small chambers <1 cm thick may have 0.1-mm resolution and thick chambers, 1-cm resolution. Space resolution of filamentary chambers depends only on filament diameter, typically ½–1 mm.

Recording dead time. The recording dead time is the time required to move the photographic film or video tape. This is much slower than the rate at which events can be studied (10^6/sec) to determine interesting events. Normal film-transport methods have recording dead time of 0.03 sec or longer. Video tape or other methods might decrease it to 0.01 sec.

Table 1 indicates the following uses for the luminescent chamber:

1. When a special particle or event cannot be separated efficiently in space from other particles or events, but can be separated by counter systems.
2. When large statistics are to be accumulated on a rare particle or event.
3. When a particle or event comes from a continuous or rapidly pulsed source, such as cosmic rays or a continuous accelerator.
4. When the time scale of an event is slower than 10^{-6} or 10^{-7} sec and the time as well as space behavior of the event is of interest.
5. When a particle flux or background to be sampled is intense

The luminescent chamber is less useful in the following cases:

1. When the number of events per second is small and background is low.
2. When the spatial resolution must be better than 1 mm in large volumes or better than 0.1 mm in small volumes.
3. When it is more economical to scan many pictures for a few events.
4. When the event must occur in liquid hydrogen and it is not suitable to use a luminescent chamber surrounding a liquid-hydrogen target.
5. When a simple scattering can be easily studied with counter arrays.

The complex scintillation-counter array included in Table 1 can approach track-recording devices in angular coverage and spatial resolution. A merging of the filamentary chamber with the counter array is likely to occur.

TABLE 1—Comparison of Track-Recording Devices

Device	*Max. time resolution (sec)*	*Counter control*	*Spatial resolution (mm)*	*Sensitive volume material*		
				Pure hydrogen	*Contain hydrogen*	*Dense high Z*
Luminescent chamber	10^{-6} to 10^{-7}	Yes	1	No(?)†	Yes	Yes
Bubble chamber	10^{-2}	No*	0.1	Yes	Yes	Yes
Cloud chamber	1	Yes	1	Yes	Yes	Multiple-plate chamber only
Nuclear emulsion	10	No	0.001	No	Yes	Yes
Complex scintillation counter array	3×10^{-9}	Yes	10	Yes	Yes	Yes

* The rapid-cycling bubble chamber, which may be expected to cycle ~ 10 times/sec with a 50% duty cycle, can be counter controlled in the sense that the lights can be flashed only during that particular cycle when counters indicate a picture should be taken. However, within a given cycle all tracks in the chamber are recorded if any are recorded.

† It may be possible to have liquid hydrogen scintillate by proper impurities addition. There are also no clear data on the scintillation properties of pure liquid hydrogen.

chambers of both NaI(Tl) and plastic should be noticed.

We have used NaI(Tl) chambers up to 6 cm thick and 8 cm in cross-sectional dimension. Photographs of minimum-ionizing tracks (Fig. 1) in such a chamber have been obtained consistently using a 1.6-cm-diameter first cathode.

Depth resolution. The depth-resolution problem in future large homogeneous chambers may be attacked in several ways. First several intensifying systems may be used to view the chamber at different depths. Thus by doubling the number of intensifier systems, the depth of the chamber can be doubled.

A second approach is to find a more efficient scintillator. There are reports (*6, 7*) that unactivated CsI when cooled to liquid-nitrogen temperatures has a very high scintillation efficiency. One might expect 10^6 photons per centimeter of minimum-ionizing track giving chambers of 2 or 3 times the resolution of the same size NaI(Tl) chambers.

Finally there is the question of whether effects such as a radiation-induced electroluminescence (*8*) could be found with the very short time constants required for luminescent-chamber work. The effects now known are all much too slow and also have large backgrounds. The fundamental limitations of the chamber all stem from the fact that the energy amplification is accomplished external to the scintillator rather than along the particle track as in the nuclear emulsion, cloud chamber, and bubble chamber.

Filamentary Chamber

Another way to collect the light from the scintillator is to use the fiber optics principle. The filamentary chamber (*9, 10*) consists of a bundle of scintillation filaments, one end of the bundle ideally being pressed against the first photocathode of the image-tube system. For stereoscopic projection, the chamber would consist of trays of scintillation fibers laid in alternate right-angle directions as shown in Fig. 3.

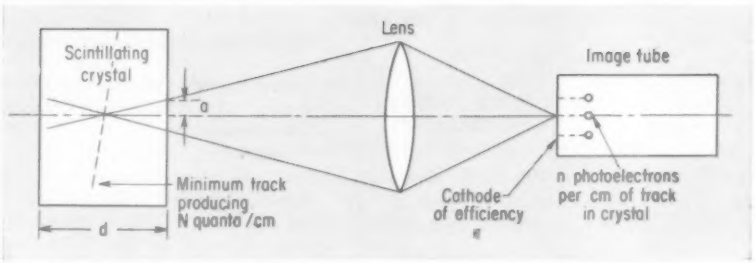

FIG. 2. COLLECTING OPTICS for homogeneous luminescent chamber system

The resolution of the filamentary chamber is equal to the diameter of the scintillation fiber. The number of recorded photons per centimeter of scintillator track, p, depends upon the attenuation characteristics of the fibers and their scintillation efficiency. To transfer light from the scintillator filaments to the photocathode, a glass-fiber faceplate on the image tube can be used as shown in Fig. 3. Alternatively, a very fast lens or corrected mirror system to couple the filamentary chamber to the photocathode can be used instead of the fiber faceplate. A third possibility involves using cathode windows of a thickness comparable to the filament diameters. Taking into account the loss in these coupling systems and the light-trapping efficiency of the filaments

$$p \cong 0.004\, N\, e^{-d/\lambda} \qquad (3)$$

where p is the number of recorded photons per centimeter of track in the chamber, λ is the attenuation length in the fiber (which is much shorter than the bulk attenuation length due to the multiple reflection losses at the walls) and d is the track depth in the chamber. For 1-mm-diameter plastic fibers, λ is currently 5–30 cm, depending on the fiber surface. It is also useful to consider the photons recorded per 1-mm-diameter filament, q, by a minimum ionizing particle at the rear of the chamber.

$$q \cong 0.0008\, N\, e^{-d/\lambda}$$

Table 4 presents the parameters of several filamentary chambers consisting of 1-mm-diameter filaments.

It can be seen from Table 4 that plastic filamentary chambers with 1-mm resolution are feasible with depths of 20–50 cm, depending on the fiber attenuation length. In that case there are only a few recorded photons per fiber, and it is necessary to amplify each resulting photoelectron sufficiently so that it can be recorded. Thus the same amplification is required as in the homogeneous chamber. If, however, a shallow chamber a few centimeters thick is used, and, if in particular a demagnifying intensifier system is used, then there might be sufficient photons per fiber to permit a smaller amplification to be used.

The cross-sectional dimensions of the filamentary chamber are, like the homogeneous chamber, limited by the total number of resolution elements in the intensifier system, with the added constraint that it must be no larger than the cathode dimensions of the first image tube (for either fiber faceplate or large-aperature optics).

Cosmic-ray tracks have been obtained in small (several cm thick, 1-mm fiber) plastic filamentary chambers by several groups (*11*). Pending development of fiber faceplates, the chamber is usually placed directly against the cathode envelope of the first image

TABLE 2—Properties of Luminescent Chamber Scintillators

Scintillator	*Particle-producing track*	N, *number of photons produced per cm of track in scintillator*
Plastic at room temperature	Minimum-ionizing particle	20,000
	100-Mev proton	70,000
	10-Mev proton	350,000
Anthracene at room temperature	Minimum-ionizing particle	70,000
Sodium Iodide at room temperature	Minimum-ionizing particle	110,000
	100-Mev proton	350,000
	10-Mev proton	1,500,000

TABLE 3—Parameters of Some Homogeneous Chambers for Minimum Ionizing Tracks

Scintillator	Recorded photons/cm in scintillator	Resolution in scintillators (cm)	Maximum depth (cm)	Max. cross sectional dimension (cm) for R = 10,000	f number of collecting system
NaI(Tl)	50	0.01	0.2	1	1.4
	5	0.1	7	10	1.6 onto 2-cm cathode
					4.8 onto 10-cm cathode
	2.5	0.2	19	20	4.4 onto 10-cm cathode
	1*	0.5	73	50	3.4 onto 10-cm cathode
Plastic	5	0.1	3	10	0.8 onto 2-cm cathode
					2.5 onto 10-cm cathode
	1*	0.5	31	50	1.7 onto 10-cm cathode
	0.5*	2	160	200	0.7 onto 10-cm cathode

* These numbers are a maximum for p because there is self-absorption of the fluorescent light by the scintillator. This absorption may be considerable in these very deep chambers.

tube. It has been found that care must be taken to prevent "cross-talk" between filaments.

Filament vs. Homogeneous

It is clear that the principle is sound and that satisfactory tracks can be obtained in the filamentary chamber as well as in the homogeneous chamber. The methods discussed for increasing the scintillation efficiency of the homogeneous chamber also apply to the filamentary chamber. It is probable that both moderate-size homogeneous NaI(Tl) chambers and plastic filamentary chambers will be of use. The authors have so far used the NaI(Tl) homogeneous chamber where the coupling between chamber and image tubes is relatively simple. Fiber face plates of 5 in. diameter have recently been fabricated and will soon be incorporated into image tubes with that diameter. The thin cathode envelope and large-aperture lens system are also under active development for use with filamentary chambers. Filaments of NaI and CsI may be available in the future, and it is possible that plastic homogeneous chambers may find use.

IMAGE TUBE SYSTEMS

From the previous section, it should be clear that moderate- and large-size homogeneous or filamentary chambers require sufficient amplification to record individual photons.

A sufficiently dense image on the fastest commercially available film* requires about 2×10^3 photons/cm². The best resolution currently achieved through an entire image-tube–lens system corresponds to an area of 2×10^{-4} cm². Thus a gain of at least 4×10^4 is required in the amplifying system. This amplification is achieved with image converter tubes.

A one-stage tube is shown in Fig. 3. The tube photocathode converts the light image to an electron image, an electrostatic potential of 10–30 kv accelerates the electrons to a phosphor screen, where the accelerated electrons are converted back into light. An electrostatic or magnetic focusing system must be used to preserve the electron image. The ratio of the number of photons leaving the fluorescent screen to the number of photons impinging on the photocathode is called the quantum gain and in existing tubes may be 30–100. The highest-gain one-stage tube is the Westinghouse WL7257, which has a quantum gain of

* The authors have used Kodak Royal X-Pan, Kodak 1-D(2), Agfa Isopan Record and Ansco Super Hypan. Of these, the Royal X-Pan seems the most sensitive.

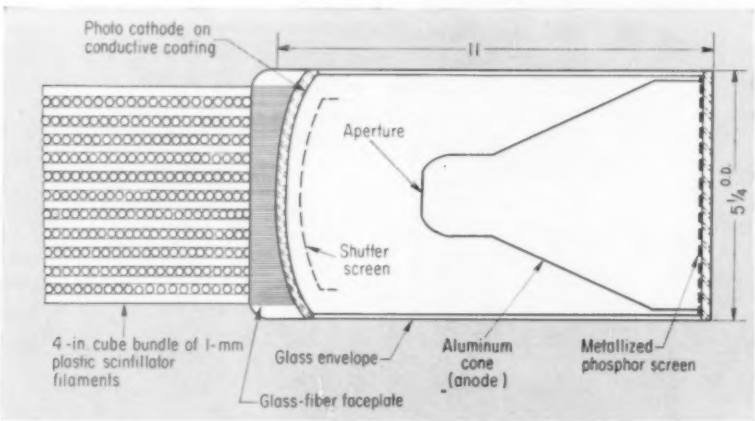

FIG. 3. FILAMENTARY SCINTILLATOR with glass-fiber faceplate between chamber edge and photocathode. Chamber can be coupled to photocathode with "fast" lens system in place of fiber faceplate. Image-intensifier tube shown is typical single-stage design

TABLE 4—Parameters of Filamentary Chambers for Minimum-Ionizing Tracks at Back of Chamber

Depth (cm)	Attenuation length (cm)	p, number of recorded photons per cm of track	q, number of recorded photons per fiber
2	5	50	10
	15	70	14
10	5	11	2
	15	40	8
20	5	1.5	0.3
	15	20	4
100	5	0	0
	15	0.1	0.02

about 80 and demagnifies from a 5-in.-diameter photocathode to a 1-in.-diameter anode.

Tube cascades. To obtain a total quantum gain of about 10^5, several tubes must then be used, with image-preserving optical coupling systems between tubes. A particularly efficient way to do this is to put several amplification stages into the same vacuum envelope, with a thin transparent membrane between the fluorescent screen of one stage and the photocathode of the next stage. Commercially available two- and three-stage tubes with unit magnification, and a gain of 30 per stage, are made by RCA.

The authors have used various tube combinations to obtain the required gain. One system is shown in Fig. 4. The NaI(Tl) chamber is demagnified by a lens of variable aperture onto the first photocathode of the first RCA tube. The refractive lenses coupling the RCA tubes have a 5% light collection efficiency. Recently it has been possible to obtain a lens pair designed for this purpose with greater than 15% coupling efficiency. The final anode is coupled to the film by a purely refractive lens with 15% coupling efficiency. The RCA tubes in use have an average quantum gain of about 900. The quantum gain of the system is thus $(900)^3(0.05)^2(0.15) = 2.7 \times 10^5$. The resolution of these tubes decreases with radius from the optical axis of the system. With only a central 1.5-cm-diameter circular area, an average resolution of 0.2 mm is obtained on the film.

At sea level, almost all of the particles that go through the chamber are minimum-ionizing cosmic-ray mesons. A photomultiplier views the chamber and indicates when a particle goes through the chamber. The first tube is always on, but the second and third tubes are gated off. The photomultiplier signal gates the second tube on for a period of 0.2–1 msec and the third tube on for a somewhat longer period. Meanwhile the first tube, whose fluorescent screens have decay times of several tenths of a millisecond, is storing the image of the particle track. During the time the tubes are on, this image is amplified and passed through onto the film.

The cascade system, when pulsed, has a gain less than 2.7×10^5 because all the light does not come out of the phosphor screens before the tubes are turned off. Therefore this system is just able to record individual photoelectrons. The tracks obtained in the homogeneous chamber (Fig. 1) are due to several dozen photoelectrons when a small-aperture chamber-viewing lens is used and roughly a hundred photoelectrons using a larger lens. Of course, in the latter case the track is broader on the average. The darker places along the tracks are due to the statistical superposition of several photoelectrons. Tracks have been recorded using several image-tube combinations; in every case a compromise between gain and resolution must be found.

Not only must the tubes be selected for highest gain, but it is necessary that their background noise be as low as possible. The background noise as seen in Fig. 1 consists of a uniform background from the last tube and several dark dots. These dark dots are due to clumps of electrons emitted by the first few photocathodes in the system. The origin of these clumps is not clear. Some are definitely due to positive-ion bombardment of the cathode, but others may be caused by local high thermal or field-emission areas on the photocathode.

The tracks from both types of chambers can be observed visually on the last tube in the cascade system. In fact when the gain of the system is too low for photography, tracks can still be observed by the dark-adapted eye with the aid of a magnifier.

A number of multistage image tubes are being developed—tubes with gains of 30,000 or more have been made. Thus ultimately one or two tubes will probably be sufficient. The later work of Zavoisky (*3*) already made use of a single multistage image tube developed in the U. S. S. R.

Another approach for obtaining a high-gain system is the regenerative use of a single image tube (*12*). A high-gain regenerative image intensifier is being developed.

Particle tracks have also been obtained by the authors using meson beams from the bevatron of the Lawrence Radiation Laboratory. The image tube sequence used consisted of a WL7257 employing a P15 fast phosphor as the first image tube followed by two or three multistage RCA tubes (C 73458 and C 73491) optically coupled by f/1.5 lens pairs. Gating times of 2–10 μsec were used where the gate triggering was controlled by a scintillation-counter telescope. Tracks recorded with this arrangement are shown in Fig. 5.

TELEVISION SYSTEMS

As the intensity of the light image is decreased on an image orthicon below the usual operating levels, the resolution of the system gets gradually worse. It is therefore not possible to specify the ultimate sensitivity of an image-orthicon system in precise numbers.

A selected best-quality image orthicon with a low-noise amplifier system following it requires 7×10^8 photons/cm²/frame for a 10-to-1 signal-to-noise ratio and 2×10^7 photons/cm²/frame for a 1-to-1 signal-to-noise ratio. Thus the image orthicon ranges from being somewhat less sensitive than film to being an order of magnitude more sensitive depending on the desired

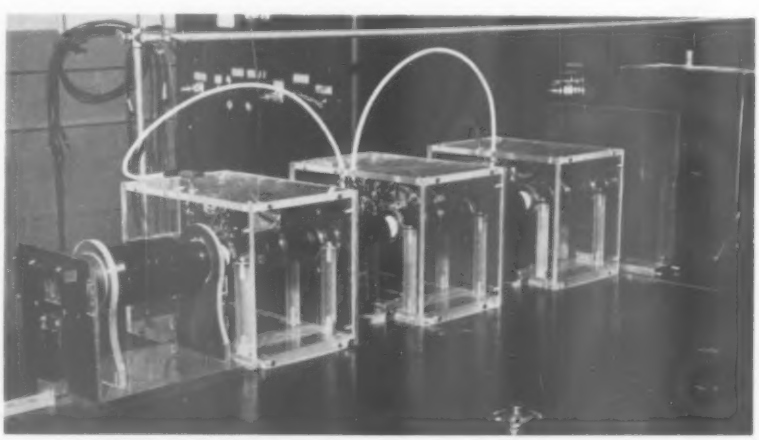

FIG. 4. CASCADED IMAGE TUBE system. Two-stage image tubes are coupled with unit-magnification lenses

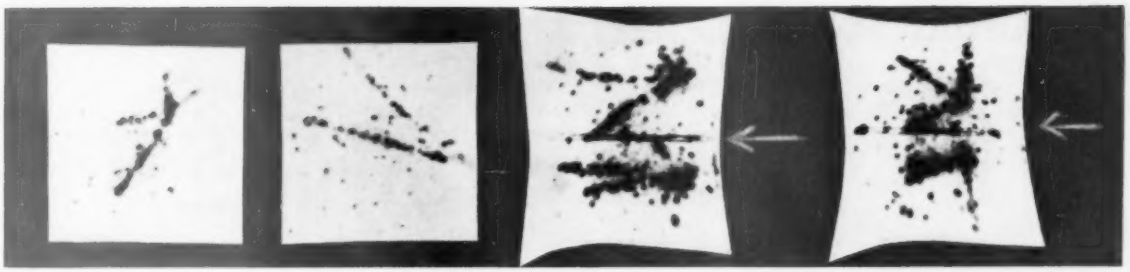

FIG. 5. TRACKS RECORDED at Lawrence Radiation Laboratory Bevatron. Two recordings at left are 1-Bev/c pions in 2.5-in.-dia. 2-in.-thick crystal. At right are 90-deg stereo views (one above the other) of 2-Bev/c pions in 4 × 2 × 2-in. rectangular scintillator; arrows indicate direction of incoming pions; pincushion distortion is caused by image tubes

signal-to-noise ratio. In any case, it is clear that the best image orthicon is not able to view a luminescent chamber directly, and one or more image tubes must be used ahead of the image orthicon.

A particularly useful combination is the intensifier image orthicon in which one or two stages of image intensification are built into the same vacuum envelope as the image orthicon. The one-stage intensifier image orthicon has been used in combination with conventional two-stage image tubes for viewing tracks in filamentary chambers (*11*).

While the amplifying system consisting purely of image tubes recording on film is less expensive and electronically simpler than an image tube and intensifier-image-orthicon system, the television system has the advantage of allowing the picture to be directly recorded on video tape. This, first of all, enables pictures to be recorded at a greater rate than on film. Secondly there will be a time when the analysis of the pictures can be performed by giving all the information contained in the picture to a computer. To have that information in the form of electrical signals coming from a video tape is much more convenient than using a television system to scan the photographic film from the pure image-tube system.

The major problem in the development of pure image-tube systems is increasing the gain and resolution while decreasing the noise. The same problem remains in the intensifier stages of a television system, and the same developments will solve the problem in either system.

While the emphasis in this article has been on the current state of the luminescent-chamber art, much improved image tubes are under development. It is reasonable to expect the recent rapid development of this new device to continue.

* * *

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13. Under the auspices of the Space Technology Laboratories, Los Angeles, California

Groups Working on Luminescent Chambers

Massachusetts Institute of Technology—expect to use filamentary chamber for elementary particle experiments within six months. They use intensifier image orthicon as the last stage of intensifier system. At present they photograph video picture, but hope to use video signal in computer through tape storage.

Princeton University—filamentary chambers and direct photography of last image tube as well as in conjunction with intensifier image orthicons. They expect to begin accelerator experiment in a few months.

Space Technology Laboratory, Inc.—building system to gain knowledge for space-satellite application.

University of Michigan—work described in this article.

University of Pennsylvania—similar to Princeton University program.

University of Rochester—mostly concerned with image-tube development and automatic handling of luminescent-chamber data.

Soviet Union—original developer of luminescent chamber, E. K. Zavoisky, is possibly no longer interested in this field. We do not know if the very fine, five-stage image tube he developed (which until very recently could not be duplicated outside the Soviet Union) is still being made. It apparently is not being used for luminescent chambers. Some activity at Dubna nuclear research center on luminescent chamber.

England—extremely good five-stage transmission-type image tube developed at Imperial College probably is as good as the Zavoisky tube. Tube will be used for accelerator experiment.

Switzerland—CERN, a very sensitive "electron bombardment induced conductivity" video tube is being developed for viewing chamber directly.

France—scintillation filaments being developed at CNR Saclay. They are planning to build chamber; so far, commercially available European tubes have not been used for this purpose.

Germany—at University of Bonn, five-stage image tubes are being developed.

SEMICONDUCTOR DETECTORS

Semiconductor junction detectors have already outstripped gridded ion chambers for alpha-particle spectral measurements. With further development they will take on many more jobs

SEMICONDUCTOR JUNCTION DETECTORS* were the big news at the Scintillation Counter Symposium. Their impressive resolution for alpha particles (Fig. 1) is rapidly being extended to beta particles (Fig. 2) and fission fragments. The physics of their operation is now coming to be fairly well understood, and detector fabrication is less fraught with uncertainties. Researchers look ahead to detectors with larger sensitive volumes (larger areas combined with deeper depletion layers). This may require use of semiconductors with larger energy gaps such as gallium arsenide and gallium phosphide and/or operation at low temperatures. This exploding technology deserves all the attention it is getting.

The principal laboratories working with semiconductor detectors were represented at the Scintillation Counter Symposium. Papers were presented by G. L. Miller of the Brookhaven-Bell Labs group, Blankenship of Oak Ridge and Mayer and Friedland of Hughes. J. M. McKenzie of Chalk River and R. W. Jackson of RCA Victor, Montreal represented the substantial Canadian effort in this field.

*S. Friedland, et al. NUCLEONICS **18**, No. 2, 54 (1960).

Fundamentals

To make a detector one starts with a small (<1-cm²) die of semiconductor silicon perhaps 1 mm thick. Then one creates a rectifying junction in the silicon in one of two ways: In the first method a donor material (phosphorous is most commonly used) is diffused into *p*-type silicon so as to create an *n*-type region at the surface of the silicon wafer; in the second method the surface of *n*-type silicon is chemically etched and coated with gold by evaporation to produce an extremely thin *p*-type "inversion layer"—this is the so-called surface-barrier approach. Leads are attached to the base material and to the surface adjacent to the junction material, thus producing a diode.

If a reverse biasing voltage is applied to the diode an electric field will be established at the junction and only a small leakage current (of the order of a fraction of a microampere) will flow across it. Within the silicon essentially all of the reverse biasing voltage appears across the so-called depletion layer—a region on either side of the junction. The depletion layer is the sensitive region of the device, and if charge carriers are generated within it by the passage of a nuclear particle they will be swept apart even as they are in a gas-filled ion chamber (see Fig. 3).

One significant difference is that the density of the medium is much greater than that of the gas of ion chambers, thus the ranges of heavy particles are measured in microns rather than centimeters (see Fig. 4 for range curves).

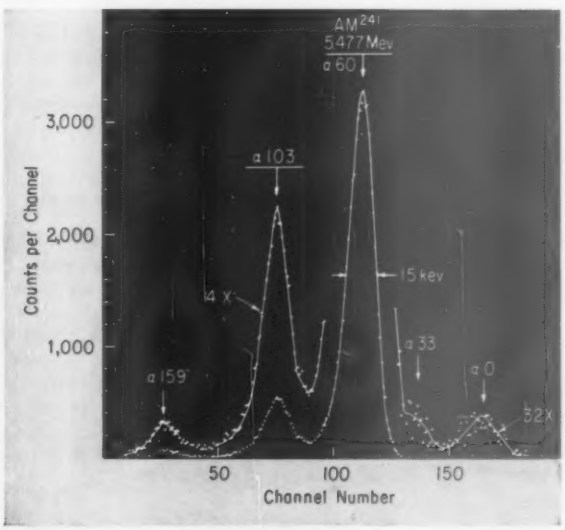

FIG. 1. REMARKABLE RESOLUTION in fine structure of Am^{241} 5.477-Mev alpha-particle line, better than that attainable with gridded ion chambers, was achieved at Oak Ridge. Detector area was 6.3 mm², bias was 15 v

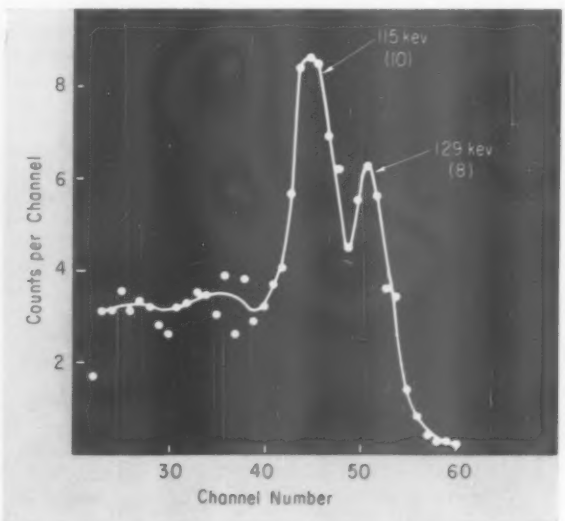

FIG. 2. BETA PARTICLES, TOO, can be detected with semiconductor detectors. Here betas from Co^{57} are measured with 10-mm² Chalk River *p-n* junction detector made by diffusing phosphorus into 12,000-ohm-cm silicon

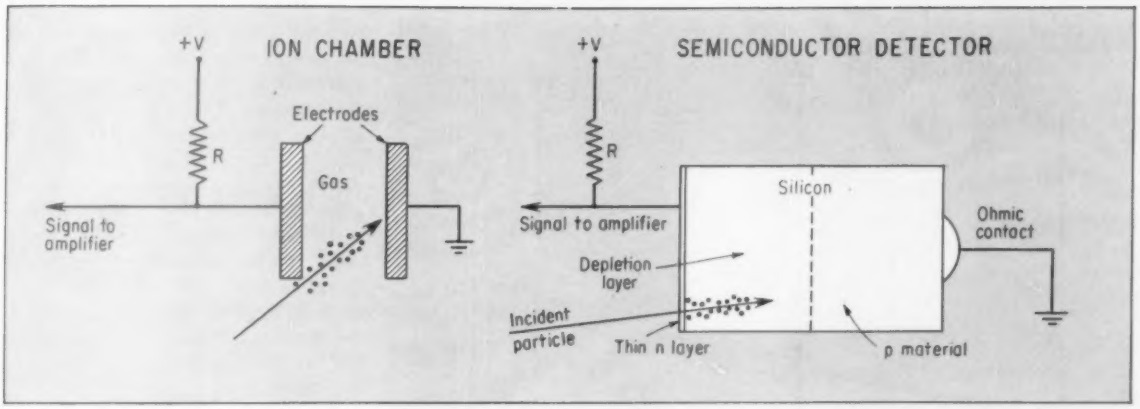

FIG. 3. SOLID-STATE ION CHAMBER is name frequently applied to semiconductor detectors because of their similarity to gas-filled ion chambers, as shown here. But density is greater, dimensions smaller and energy required per ion pair much less

Still another difference is in the nature of a complication. The width of the depletion region, which corresponds to the distance between the parallel plates of a simple ion chamber, varies as the square root of the applied bias voltage. Correspondingly the device junction capacitance is proportional to $V^{-\frac{1}{2}}$. Thus semiconductor junction detectors are like ion chambers whose plates move as a function of applied voltage. The governing relationships have been sorted out into a very useful monogram by Blankenship of ORNL that is given here as Fig. 5. (A wall-size version is available from ORNL's Tech. Information Div.).

Another important consideration is that it requires only 3.5 ev to produce an electron-hole pair in silicon, as opposed to 28 ev for an ion pair, in, say, argon gas. Thus for the same amount of energy deposited in the sensitive volume of each detector there will be eight times as much charge produced in the silicon and, if the detector capacitances are comparable, eight times as much signal voltage. The standard deviation, based on the number of charge carriers produced, is reduced by $1/\sqrt{8}$. Not only are solid-state detectors theoretically capable of better resolution than ion chambers, they are already yielding better performance. Another important factor is that semiconductor detectors are much easier to use than gridded ion chambers.

Results with Alpha Particles

Because alpha particles have a range in silicon comparable with the thickness of the sensitive depletion layer and because monoenergetic sources are conveniently available, alpha particles have been the principal tool for testing semiconductor detectors.

Each of the groups reported alpha-particle resolution that at least compared favorably with all but the most precise ion chambers, and the Oak Ridge group reported it had beaten the resolution of the best of ion chambers using a 6.3-mm² surface-barrier counter (Fig. 1). The resolution of 15 kev was limited by factors other than amplifier noise, since the equivalent input noise of the amplifier was 7.5 kev (full width at half maximum) for a total input capacitance of 50 $\mu\mu$f. Therefore the intrinsic resolution of this counter was 13 kev. The fine structure may be seen for the $\alpha 0$, $\alpha 60$, $\alpha 103$, and $\alpha 159$ lines. The ratio of the areas under these lines are in agreement with magnetic-spectrograph data. The peak-to-valley ratio for the $\alpha 103$ line has been found to be a useful measure of resolution in the range of 15–20 kev. These lines would not be seen with a Frisch-grid pulse-ion chamber, since the best energy resolution that has been obtained with this detector is 26 kev.

Detection of Beta Particles

With a thick depletion region close to the surface, beta particles in the range from 10 kev to several hundred kev are detectable. The pulse-amplitude distribution from Co^{57} (Fig. 2) obtained at Chalk River indicates the presence of the two well-known lines at 115 and 129 kev. This and similar Chalk River results with other beta emitters were obtained using a 10-mm² *p-n* junction made 12,000-ohm-cm *p*-type silicon. With 3C-v bias 180 kev β-particles stop in the depletion layer.

Fission Fragments

Owing to their high initial charge state, fission fragments lose most of

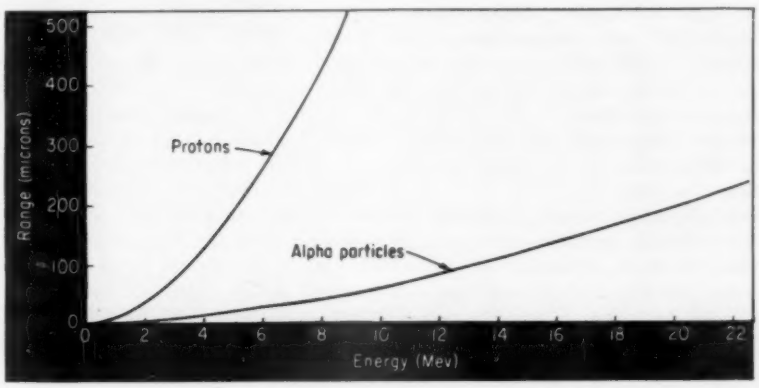

FIG. 4. RANGE-ENERGY curves for alpha particles and protons in silicon

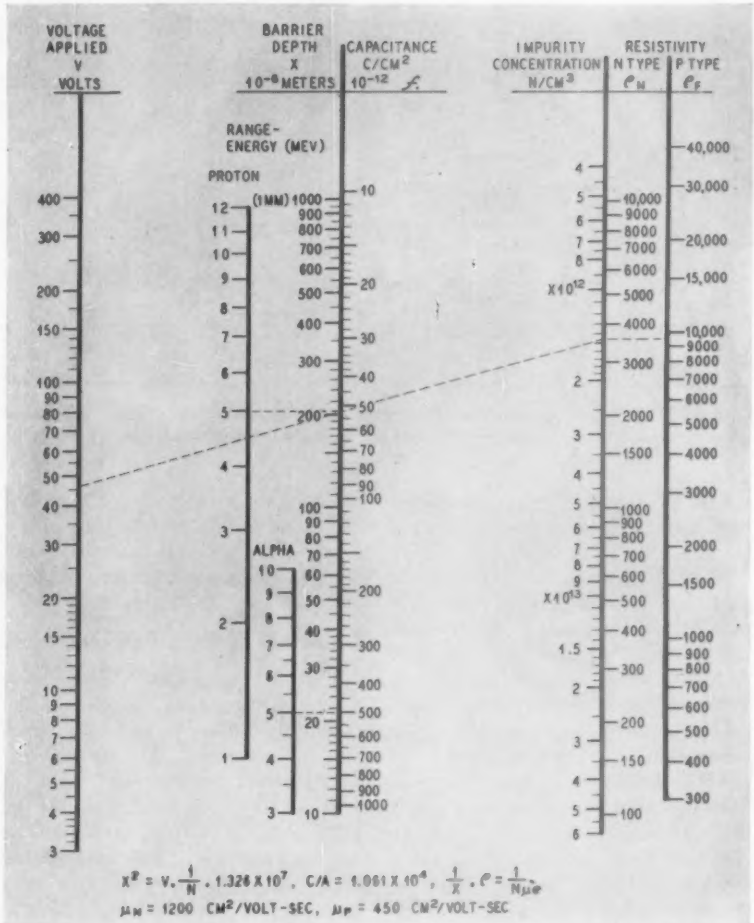
VOLTAGE APPLIED V VOLTS
BARRIER DEPTH X 10^{-6} METERS
CAPACITANCE C/CM^2 10^{-12} f
IMPURITY CONCENTRATION N/CM^3
RESISTIVITY N TYPE ρ_N
P TYPE ρ_P
RANGE-ENERGY (MEV)
PROTON
(1MM)
ALPHA
X10^{12}
X10^{13}
$X^2 = V_o \frac{1}{N} \cdot 1.326 \times 10^7$, $C/A = 1.061 \times 10^{-4}$, $\frac{1}{X} \cdot \rho = \frac{1}{N\mu e}$
μ_N = 1200 CM^2/VOLT-SEC, μ_P = 450 CM^2/VOLT-SEC

FIG. 5. SILICON-JUNCTION DETECTOR behavior is governed by equations that can be solved with the aid of this nomogram. In example shown, for 3,600-ohm-cm *n*-type silicon with 45 v reverse bias the capacitance is 52 $\mu\mu$f for a 1-cm^2-area detector and the effective depletion layer is 200 microns, about the range of a 5-Mev proton

their energy in the extreme surface of a detector. It therefore is necessary to use an essentially "windowless" detector, i.e. one having a zero *n*-region dead layer even for heavily ionizing particles. While some *n*-type region is inherent in a diffused-junction device it can be made very thin (down to 0.1 microns) and then only a very short carrier lifetime will suffice for carriers to diffuse to the junction and be collected.

The Brookhaven group measured the Cf^{252} fission spectrum using a 0.1-micron-*n*-layer diffused-junction device. Their results agree with the best time-of-flight data within the experimental accuracy of both results. Two conclusions are drawn from this agreement. First that ϵ, the number of ev per hole-electron pair is the same for fission fragments as for other particles; this follows from the correctness of the energy difference between the peaks. And second that the device must indeed have a negligible dead layer, for if this were not the case the absolute energies would be lower, i.e. the entire curve would be shifted to the left.

Incidentally these results also show that these detectors do not exhibit the "ionization defect" characteristic of gaseous ion chambers. Evidently also there exists negligible columnar recombination along the track of the fission fragment; even though the peak carrier density in this region $\sim 10^{20}$/cm.

However, in another experiment designed to measure the speed of charge collection the BNL group observed a rise time from fission fragments of 10 nanosec as opposed to an expected $\sim$2 nanosec. This is well outside any experimental error. It is thought that this result is due to ambipolar effects—the high-carrier-density track left by a fission fragment can be pictured as a highly conducting plasma. This plasma, being a conductor, does not allow the electric field in the depletion region to enter it and sweep the carriers away to be collected. Carriers are therefore only collected by "erosion" from the extreme plasma surfaces, leading to relatively slow rise times, though still very rapid by ion-chamber standards.

Heavy Ions

S. Friedland reported on results obtained by Gordon et al. at Berkeley on the response of Hughes diffused-junction detectors to carbon ions having energies up to 120 Mev. The output pulse height is very linear with particle energy and agrees with the output for fission fragments of the same energy and the extrapolated response to alpha particles of much lower energy. This further demonstrates the absence of an ionization defect in these detectors.

Amplifiers

The Brookhaven-Bell Labs group pointed out that the magnitude of the detector output signal is (inconveniently) a function of the applied bias since the detector capacitance is bias-dependent. Furthermore the quantity of interest is not actually the voltage but the total charge. Therefore they use a charge-sensitive amplifier in conjunction with their semiconductor. The amplifier consists of a gain-of-1,000 preamplifier stage with a 5-$\mu\mu$f feedback capacitor.

The output voltage from the preamplifier is just $Q_C/5 \times 10^{-12}$ volts, i.e. is independent of the device capacitance. Of course, the application of feedback cannot change the signal-to-noise ratio of the detector.

The Oak Ridge group uses its Q-2609 "Linear Amplifier and Preamplifier for Alpha Energy Analysis" with E83F low-noise cascode input stage, easily variable double clipping and post amplifier with adjustable clipping (circuit diagrams are available from Technical Information Division, ORNL). Clipping times of 0.5–2 μsec give optimum signal-to-noise ratio.

For low-resolution applications Chalk River uses transistor amplifiers.

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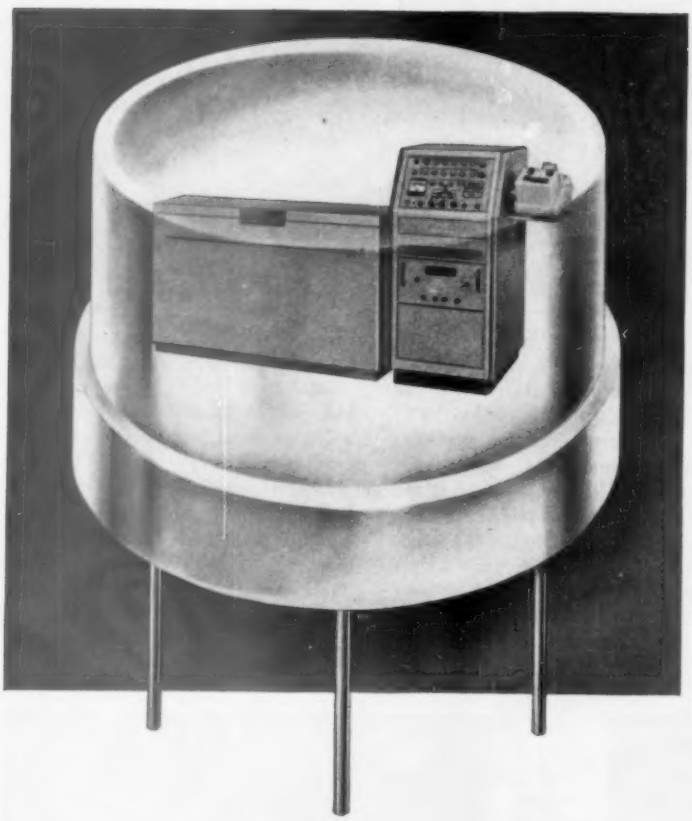

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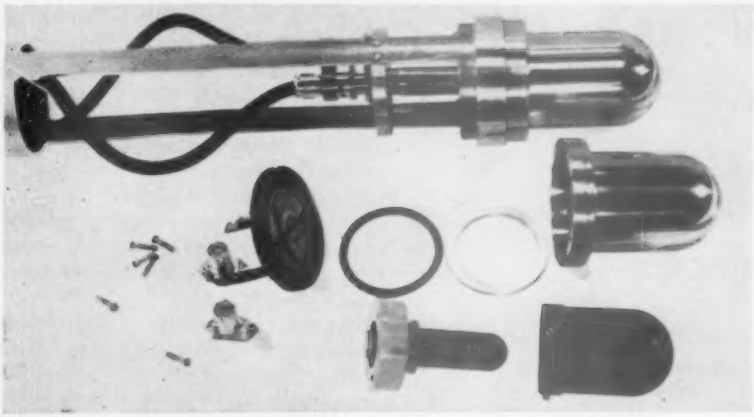


FIG. 1. HIGH-LEVEL ION CHAMBER is readily disassembled. Amount of material behind chamber is kept to minimum to make chamber less directional

Ion-Chamber Response in High-Level Radiation Field

By E. G. BYLANDER*
Convair-Fort Worth Division, General Dynamics Corp., Fort Worth, Texas

An adaptation of an ORNL ion-chamber design (*1*) has performed satisfactorily in a high-level gamma-ray field. It can be used for dose rates up to 4×10^{10} ergs/gm/hr. Neutron sensitivity is sufficiently low and agrees with theory for neutrons up to 14 Mev.

The Nuclear Aircraft Research Facility at Convair-Fort Worth began a search for such a chamber at the request of a committee set up by the Air Force to recommend standard techniques in radiation measurement. The committee set the following criteria for instrument performance: (1) as nondirectional as possible; (2) known temperature response between 0° and 100° C; (3) neutron response known and as low as possible; (4) capable of withstanding 10^{12} ergs/gm(C); (5) sturdy and simple construction; (6) linear to ±½% over the range 10^5–10^{10} ergs/gm(C)/hr. All these criteria but the last were met.

* PRESENT ADDRESS: Texas Instruments Incorporated, Dallas, Texas.

Modifying the ORNL Chamber

An ORNL design for a 4-cm³ ion chamber (*1*) was chosen as a start, and a model was built to this design.

Over a period of a year, the ORNL chamber was modified mechanically to improve its resistance to radiation and to decrease its size and complexity.

A flow chamber and a static chamber of the modified design were built retaining the ORNL electrode configuration (0.250-in. wall thickness and 0.125-in. spacing) of the covered ORNL model. Thus the electrical properties of the chamber were not changed. Calculation showed the wall provided electron equilibrium for reactor radiation.

Final Chamber Design

The finished ion chamber (Fig. 1) is simpler and requires less parts than the original design. It is made of aluminum, polystyrene, fluorethene and graphite. It is readily disassembled by removing the brass end-plate on which all parts are mounted.

The chamber could be made more radiation resistant by the use of a quartz center insulator (cost: about $75), a Mykroy high-voltage insulator and a metal "O"-ring seal. So far, Teflon has proved the best connector insulation for doses up to 10^{11} ergs/gm. For higher doses, an especially designed quartz-insulated cable is used to carry the signal outside the high radiation zone to a point where conventional polyethylene-insulated cables can be used. The cable consists of a capillary quartz insulator inside an aluminum tube. No connectors are used—the quartz insulator extends inside the

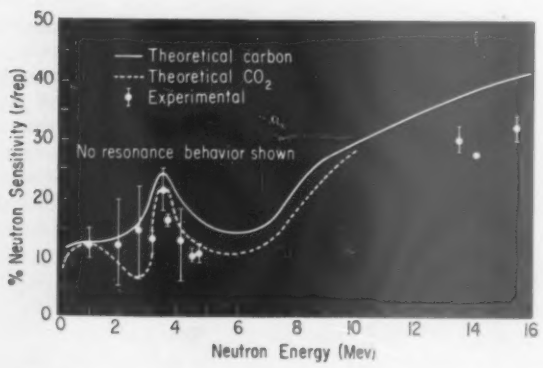


FIG. 2. NEUTRON-DOSE SENSITIVITY of chamber (operating conditions: 900 volts, 26° C, 36 in. Hg abs.)

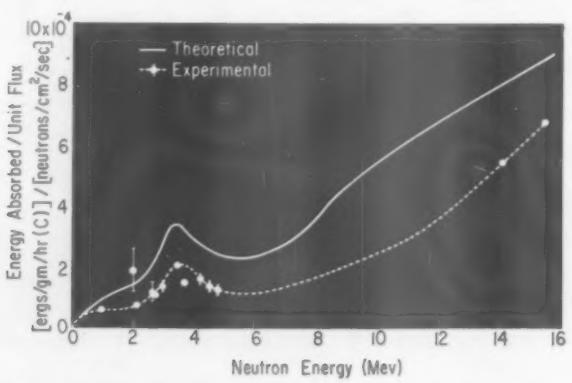
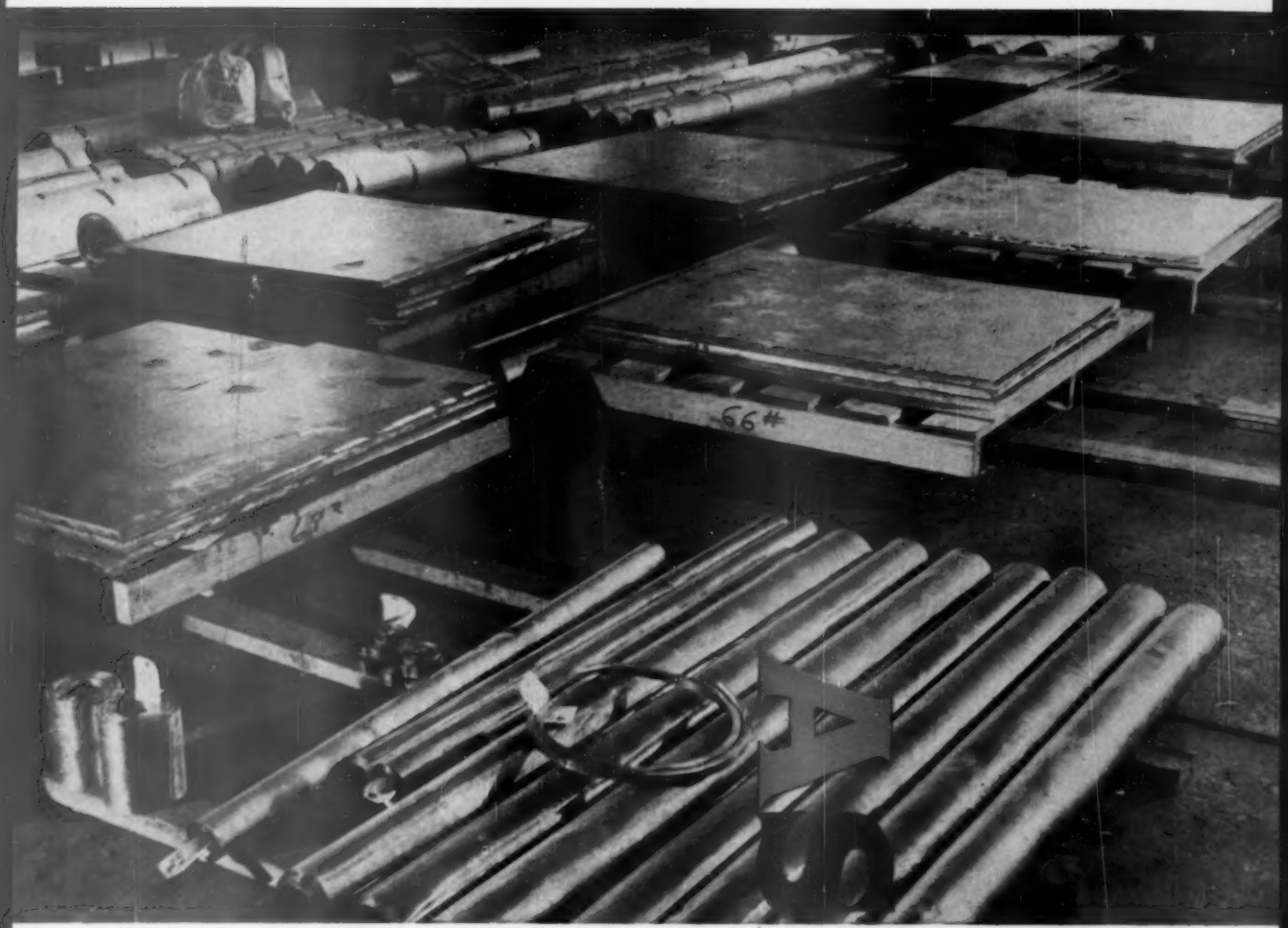


FIG. 3. ENERGY ABSORBED in chamber (same conditions as Fig. 2)



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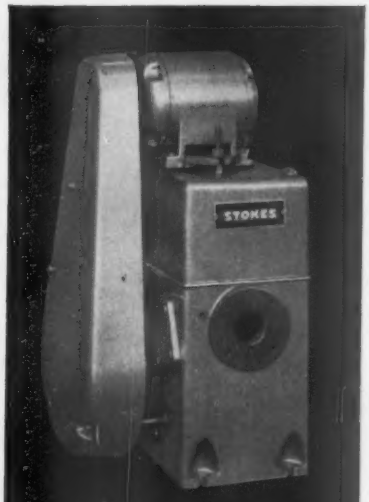

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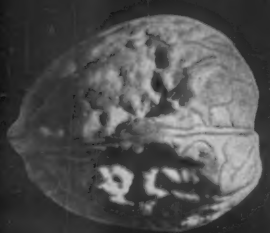

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chamber and serves as part of the ion-chamber insulator.

Instrumentation

To test the chambers a special instrumentation system was built. The over-all system is ±10% accurate, ±5% linear and ±1% precise. Most of the nonlinearity of the system is caused by errors in switching between micromicroammeter ranges. Work is being done with a rate-of-charge device to improve linearity over 5 decades. Care must be taken with cable routing to avoid radiation-induced cable currents, which may amount to as much as 10^{-10} amperes/ft for polyethylene-insulated RG59. This system has achieved ±0.3% precision over a 6-month period.

A temperature- and pressure-correction calculator corrects ion-chamber readings automatically to 0° C and 760 mm Hg.

Chamber Characteristics

Temperature sensitivity. Tests with the flow chamber showed that the temperature of the gas matched that of the detector for flow rates up to 2 ft³/hr. Under this condition, the detector output varies inversely as the detector temperature (and directly as the pressure).

In a pure gamma field, it is convenient to use the chamber as an open-air chamber. In this case, the output again varies as the gas population, or as the ratio of absolute pressures and temperatures.

The static chamber has proved so far to be temperature-sensitive, probably because of outgassing of the carbon electrodes with rise in temperature.

Linearity. Ion-chamber linearity was found by determining the voltage at which ion collection decreased below 99% and at which multiplication had increased by no more than 1%. For such a determination, the complications introduced by columnar recombination effects in neutron-contaminated fields (to be discussed below) made it necessary to use pure gamma fields.

The highest available "pure" (i.e., less than 10^4 photoneutrons/cm/sec) gamma field is at the MTR Gamma Facility and is of the order of $2\text{–}4 \times 10^9$ ergs/gm(C)/hr. Since this is less than the 10^{10} ergs/gm/hr desired, Boag's theory (*2*) was used, by which ion-chamber saturation can be measured at one dose rate and extrapolated to other dose rates of interest. The extrapolation procedure does not include space charge, gas contamination and change in voltage for 1% multiplication effects, which are calculated to become significant for dose rates of about 10^{10} ergs/gm/hr. The measurements at the MTR and in the 3,000-curie Co^{60} irradiator at Convair-Fort Worth, using $10^6\text{–}10^9$ ergs/gm/hr, show this method to be valid. The results indicate that the chamber can be used in dose rates up to 4×10^{10} ergs/gm(C)/hr with a 5,000-volt collecting potential at 1,000-mm absolute pressure and to 2×10^{10} ergs/gm(C)/hr with 3,000 volts at 760 mm.

Neutron Response

When a carbon ion chamber is to be used in a mixed-radiation field, its neutron sensitivity must be known. Hurst has estimated (*3*) the neutron sensitivity to be 15–50%, depending on the incident-neutron energy. At 15% sensitivity, 1 rep of neutrons gives rise to a current corresponding to 0.15 r of gamma radiation. Figure 2 shows measured and calculated (Hurst calculation) neutron sensitivity.

To measure the neutron sensitivity of the modified ORNL 4-cm³ ion chamber, neutrons were obtained with less than 1% gamma-ray background using T-P, D-D and D-T reactions (*6*).

Figure 3 gives the neutron energy absorbed per unit flux. Since recombination effects are present, which are independent of dose rate, the collection efficiency at various voltages was measured. The data of Figs. 2 and 3 were taken at 900 volts; the correction factor is roughly a linear increase with voltage and less than 8% for a voltage of 2,500 volts.

* * *

Grateful acknowledgement is made to Hermond Lacy for detector design, J. R. Gardner for computer design and K. R. Spearman for helpful discussion; also to the Convair Nuclear Instrument Group, to D. Hunke and others of the MTR Gamma Facility, and to I. L. Morgan and others of the Texas Nuclear Corp. for their help with the measurements described.

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Title: *Nondestructive Testing Handbook*. Editor: Robert C. McMaster, The Ohio State University. Publisher: The Ronald Press Company, New York. Price: $24. No charge for the applause rendered the work here. What's good for nondestructive testing is good for Kodak.

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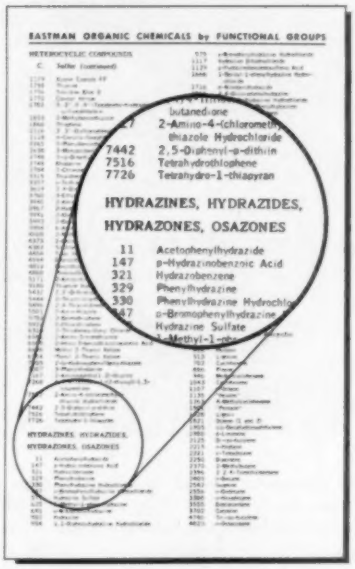
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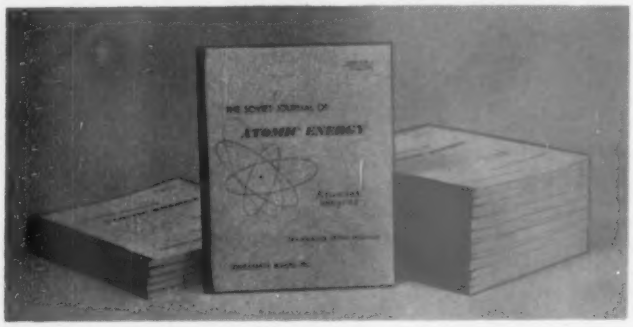

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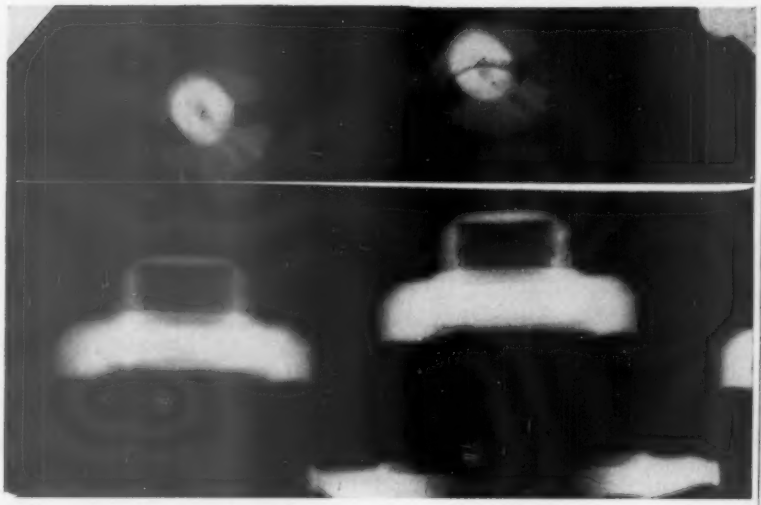

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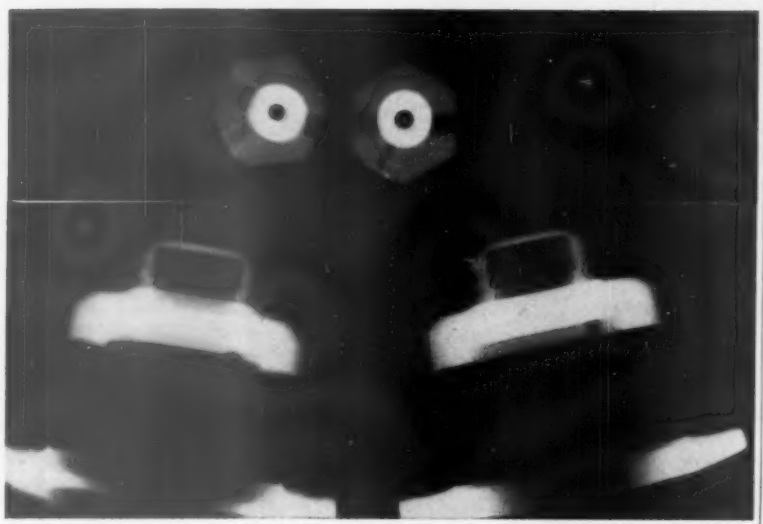

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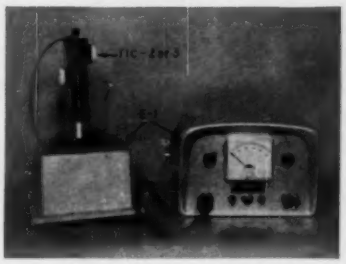

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● Process and space heat consumes 2 to 3 times as much U. S. energy as does electricity generation.

● Chemo-nuclear reactors offer promise of economically making chemicals and fertilizers that are vital in underdeveloped regions of the world.

● Practical propulsion and power for satellites, space stations and ocean-floor exploitation require use of the unique features of nuclear energy.

These three points clearly are guidelines in charting the course of advanced reactor development in this decade. In recent years, our focus on achieving economic central-station electrical generation has obscured the need for attention to these unique applications. Thus, the objectives of the reactor field today can be divided into three overall segments: (a) achieving an industry soundly based on economically competitive applications, (b) laying the experimental foundations for the high-temperature advanced reactors stressed here, and (c) preparing for the day about 25 years from now when full-scale uses of reactors will make breeder reactors and waste disposal emerge as essential factors in our nuclear economy.

The search for clarification of these guidelines was the objective of recent hearings conducted by the Joint Committee on Atomic Energy. The eight panelists testifying were: Karl Cohen of General Electric, David B. Hall of Los Alamos, Bernard Manowitz of Brookhaven, Harry P rry of the Bureau of Mines, John W. Simpson of Westinghouse, Bernard Spinrad of Argonne, Chauncey Starr of Atomics International, Alvin Weinberg of Oak Ridge, and Walter H. Ninn of Combustion Engineering.

Unique Features

By looking at "unique" reactor characteristics that promise performance "cheaper, better, or more efficient than known alternates," the problems and ultimate goals of advanced reactors were set into patterns by Spinrad; other panelists stressed particular applications, problems and solutions. Some of the uses, such as propulsion and central-station power, are being developed intensely now, others are logical outgrowths of present work, and for some we need to uncover the interrelated fundamentals of process dynamics, materials preparation and behavior that lead to reactor experiments demonstrating technical feasibility. Radiation processing and high-temperature process heat are prime examples of these.

Straightforward uses could be with plants, such as APPR and ALPR, which might be useful in disaster relief, as well as in supplementing conventional power in the lumber industry or in meeting central-station peak loads where the cost of intermittent power is high. Since reactor power level easily can be regulated over factors of at least a quadrillion (10^{15}); only system auxiliaries usually cause limitations on rate of power change.

Heat

If we can devise reactors and fuel cycles that preserve the intrinsic low cost of nuclear fuel, changes in the climate over a small area might be effected at reasonable cost. For instance, a big 100-Bw low-temperature-reactor station might heat air and dissipate smog caused by an inversion layer and combustion products in a congested area such as Los Angeles; the reactor also could distill sea water.

Without the inherent temperature limitations of chemical fuels, nuclear heat depends only on the structural and process materials involved. Bu-Mines and AEC are studying high-temperature processing of materials, such as coal carbonization and coal gasification to make CO and H_2 for producing organic chemicals and substitutes for natural gas and petroleum products. The present goal is the development of a reactor to heat helium to 2,000–2,500° F and to transfer the heat to process streams. Temperature potential of most existing designs of high-temperature reactors (such as Los Alamos' Turret) is limited because heat is generated in a solid and then is transferred to the process gas; higher temperature might be achieved if the fuel is suspended in and circulated with the process gas. Thermionic and thermoelectric systems are likely to become highly efficient above flame temperatures—thus giving unique attractiveness to nuclear systems.

For a space station, an efficient high temperature reactor might serve as an artificial sun radiating heat directly

to the working location—but this *is* a rather advanced possibility.

Chemonuclear Processing

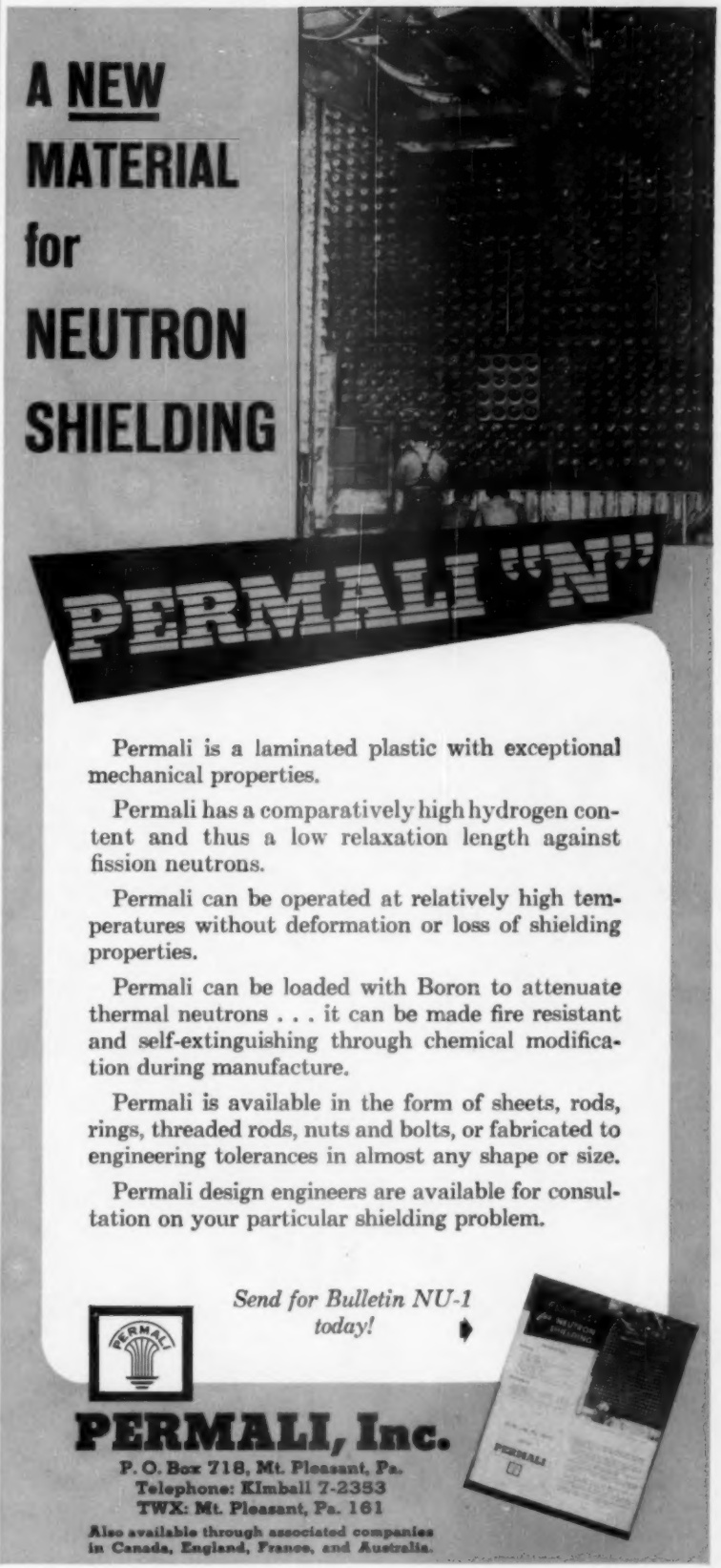
About six times as much kinetic energy from fission is released via fission fragments as in the neutrons, betas and gammas. To use this direct source of ionization energy requires development of unclad fuels having large surface-to-volume ratios. Brookhaven studies of processes for producing nitrogen oxide by exposing air in a reactor considered three configurations of nuclear fuel: UO_2 dissolved in very thin filaments of glass wool, UO_2 thinly plated on very thin flat ribbons, and a dispersion of very fine UO_2 particles in a circulating gas. Other possibly practical processes include the mine-site reduction of ores to metal by using reactor-produced nitric acid, or production of ethylene glycol from methanol, or phenol from benzene, water and oxygen. Economic analyses so far indicate that such chemonuclear processes would be marginal except where steam costs more than 40¢/MBtu or where on-site processing would lower shipping costs.

BuMines has found only minor effects from irradiating coal before subjecting it to various processes, but is continuing these experiments with irradiation during processing in the belief that larger effects will occur, particularly in the cases of carbonization and reaction with certain liquids.

Chemical intermediates might be used to store energy that would be released later via combustion, but such use of chemical compounds or solid-state devices does not seem very practical. By having fission fragments, which are ions, perform useful work against an electrical field, electricity might be generated directly. But the most probable payoff of reactors' ionization energy rests in the chemical industry.

Propulsion, Power

APPR- and ALPR-type reactors can enormously extend the capabilities of remote areas such as the Antarctic. Improved reactors can power satellites (SNAP-8) and propel space ships (Rover). But to power self-sufficient bases on other planets we will need reactors and systems that are extremely rugged, compact, and powerful. Fast-reactor systems seem ideal for this, particularly in view of EBR-2 type processes for repurifying and reconstituting spent fuel.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Current Simulates Fission Heat in Fuel-Element Test Loop

By P. E. BISSONNETTE and J. B. CARR, *Knolls Atomic Power Laboratory,* Schenectady, New York*

Heat-transfer tests on new fuel-element configurations are facilitated by the lack of radiation hazards in a 2,500-psi 650° F water flow loop in which 1.2 Mw of fission heat is simulated by direct-current power passing through the resistance in the material in test fuel elements.

Reactor performance depends heavily on the ability of the coolant to remove heat generated in the fuel elements. Thus it is important to establish experimentally the heat-transfer and fluid-flow characteristics of proposed new fuel designs. The Fuel Element Heat Transfer Loop shown in Figs. 1 and 2 subjects full-size fuel prototypes to reactor operating situations, such as steady-state, transient or casualty conditions of flow, pressure, temperature, heat flux and water chemistry.

By using direct current instead of fission to generate heat in the fuel elements, bulky shielding and complex radiation-protection devices and procedures are unnecessary, cost is reduced sharply and precise data can be obtained. The fuel prototype can be fabricated of any material having the desired electrical resistance and mechanical properties. The fact that direct current generates heat uniformly, instead of nonuniformly as in actual reactor fuel elements, must be compensated for in designing the test or in evaluating the data.

The loop is used to determine heat-transfer coefficients, maximum heat flux, two-phase pressure drop and other characteristics of various fuel-element geometries. Other investigations include simulation of reactor casualties such as power transients, loss-of-coolant and loss-of-flow accidents, and observation of the heat-transfer behavior during these incidents.

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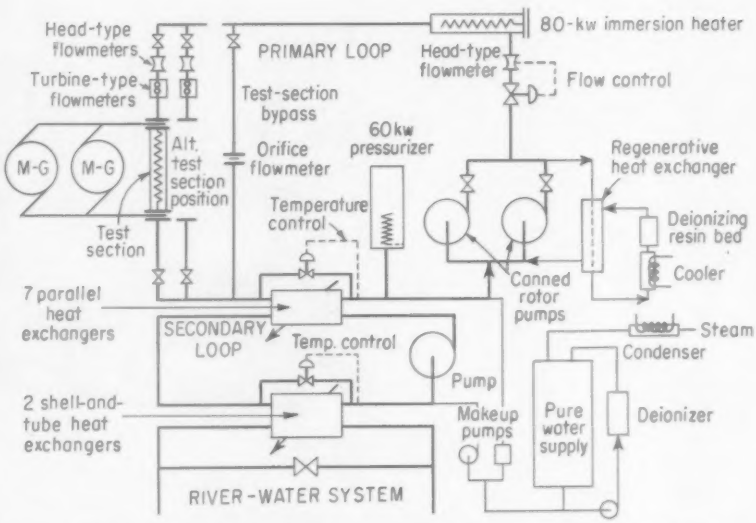


FIG. 1. KAPL'S TF-12 FUEL-ELEMENT HEAT-TRANSFER LOOP consists of closed primary and secondary piping systems whose pumps circulate cooling water through several heat exchangers to remove heat from the test "fuel" elements, a pressurizer, in-line immersion heaters for preheating before startup, and equipment to control the loop, maintain water purity, and for making experimental measurements

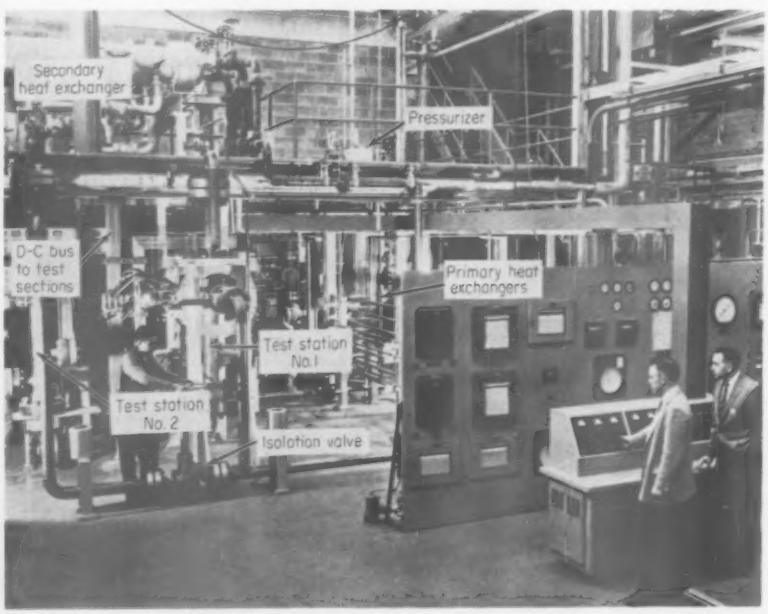
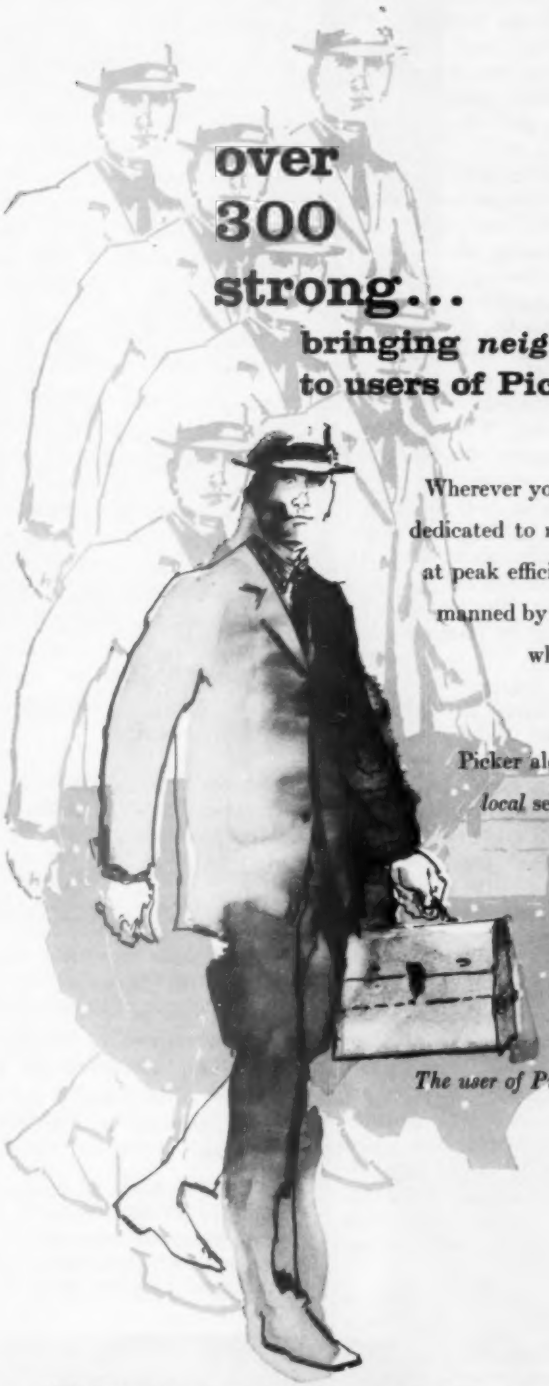


FIG. 2. ALTERNATE TEST STATIONS minimize loop downtime—one operates while the other is being prepared for another test series. Each station accommodates a test section 7¾ ft long, adequate for most fuel elements of present-day interest

* Operated for the U. S. Atomic Energy Commission by the General Electric Co.



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This article starts on page 110

volts—operate in parallel to provide the direct current to the test fuel elements. A single high-speed circuit breaker interlocked with the loop controls cuts out to protect costly test elements when their temperature nears the melting point.

The d-c generators add 1,200 kw of heat to the test fuel element; 80 kw is added to the primary-loop water by the in-line immersion heaters, and ~15 kw is added by the main pumps.

Primary Circulation

To minimize deposition of crud on the test elements, which could lead to erroneous data, the primary system consists of stainless-steel piping, tight joints and zero-leakage pumps.

Piping. The primary loop is constructed of schedule-160 3-in. and 4-in. type-347 stainless-steel pipe. Type-347 stainless steel was specified because its high-temperature strength results in light-weight flanges and low total material cost. Carbon steel was not favored because of its higher corrosion rate.

Joints. Several flanged joints enable removal of valves, flowmeters, test sections, loop filters, and other components. The 1,500-lb octagonal-ring flanges are used where joint disassembly is infrequent and where joint integrity is essential. Where frequent disassembly is required, spiral metallic gaskets are used; they offer leaktightness at low bolt torque, minimal damage to flange faces and inexpensive replacement.

Pumps. Two 150-gpm canned-motor centrifugal pumps, which can operate singly or in parallel, supply 300 gpm at 425-ft head when operating in parallel. Canned pumps were selected over the conventional gland-type limited-leakage pumps because their integrity minimizes water chemistry and make-up problems.

Heat Removal

The nearby Mohawk River is used as a heat sink (use of city water as the heat sink is out because of a limited supply in summer months). But direct river-water cooling is inadvisable without costly water treatment because the high metal temperatures in the primary-loop heat exchangers would cause rapid and serious heat-exchanger fouling. These problems are overcome by a heat-removal system of three independent, completely isolated piping systems: (a) the primary system or main loop, (b) the secondary or cooling-water system, and (c) the river-water system or heat sink. Heat goes from the primary system to the secondary system and then to the river-water system.

Primary heat exchangers. A bank of seven parallel-flow concentric-tube heat exchangers is used with the primary water flowing through the inner pipe. Flow through the heat-exchanger bank is regulated by a valve on the upstream header. A temperature-controlled bypass valve shunts hot water around the heat exchangers for loop temperature control.

Secondary system. The secondary cooling water passes through the annulus of the primary heat exchangers. The heat then is transported to the tube sides of two shell-and-tube heat exchangers piped in series, and then passes at 140° F to the river-water system. This temperature is not high enough to cause serious fouling.

The system is constructed of 4-in. copper tubing designed to operate at 150 psi and 250° F. Because the secondary system circulates deionized water through the annuli of the hot primary heat exchangers, tube fouling is much less than it would be if unprocessed river water contacted the primary exchangers.

River-water system. The river-water system, constructed of 8-in. and 12-in. carbon-steel pipe, can pump 8,000 gpm at 85-ft head through the shell sides of the heat exchangers, which are piped in parallel. (To optimize heat-transfer capabilities of the various heat exchangers, the primary exchangers are paralleled on the primary side, the secondary system is paralleled on the shell side of the primary exchangers, and the shell-and-tube heat exchangers are in series on the tube side and in parallel on the shell or river-water side.)

To minimize the temperature at which water is returned to the river (a local ordinance limits effluent to $\leq 6°$ F above river temperature), the discharge side of the river-water system includes a weir box into which all loop water is mixed before returning to the Mohawk River.

Water Supply, Purification

Both the primary and secondary systems require pure water. The

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This article starts on page 110

primary system uses reactor-grade water to simulate reactor conditions; the secondary system uses high-purity water to minimize the formation of scale on the surfaces of the heat-exchanger tubes.

Pure-water supply. To obtain high-purity water, building steam is condensed in a helical-coil heat exchanger; ¾ gpm of condensate flows to a 1,500-gal stainless-steel hold tank, where a blanket of nitrogen gas over the stored water minimizes oxygen absorption by the water. A 1-gpm stream continuously circulating through a mixed-resin deionizing bed maintains the water purity; as needed, hydrazine is added to the process stream to reduce its oxygen content.

Primary-loop purification. A high-pressure bypass deionizer system ensures that the primary water is maintained at reactor quality during experiments. A regenerative heat exchanger cools the water to less than 120° F before it goes to the mixed-resin bed to keep the resin from decomposing. The system can process ½ gpm and maintain water resistivity at 0.5–1.0 megohm-cm. To avoid installation of an additional pump to maintain water flow in the bypass, this loop is located across the suction and discharge of the primary-loop pumps.

Control

Loop operation normally is continuous; it is shut down only to change test sections or make repairs. This minimizes the number of thermal shocks and extends equipment life. Because of manpower limitations, and since it takes the facility about eight hours from a cold-iron startup to attain a hot isothermal condition at a predetermined test point, the loop is instrumented and automated so as to operate unattended for as long as two days.

Fail-safe interlocks are incorporated in the primary systems to protect the loop from damage under dangerous operating conditions, such as loss of flow, over- or under-pressure, over- or under-temperature, and low water level on the pressurizer. In addition, an alarm system warns of potentially dangerous or undesirable operating conditions, such as loss of instrument air and failure or inadvertent opening of the d-c circuit breakers (power to test section). Failure of water flow or pressure will open the d-c circuit

breaker so as to protect the test section from the effects of overheating.

Primary-water temperature control. To preheat the loop to operating temperature, 80 kw of immersion heat is available. After power has been applied to the test section, inlet temperature is controlled automatically by a heat-exchanger bypass valve. The preheaters are also used to maintain loop temperature when power is removed from the test section and to permit loop operation under essentially isothermal conditions for calibration purposes.

Pressurizer. A 60-kw immersion heater, mounted in the lower head of the pressurizer, maintains a preset loop pressure. The vessel, 6 ft long by 2 ft in diameter, is fabricated of carbon steel internally clad with type-347 stainless steel. Use of carbon steel as the pressure-vessel structural material reduces cost; the stainless-steel cladding on the inside surfaces of the pressurizer reduces corrosion.

Use of a steam pressurizer was selected over the accumulator method of pressurization because the former is inherently more stable; pressure fluctuations are absorbed by the pressurizer. Automatic pressure regulation is provided by control of power to the pressurizer heater.

Motor-generator sets. To minimize high in-rush currents at startup, which would disturb other facilities on the same a-c power-distribution system, auxiliary oil pumps reduce the friction load by floating the three journal bearings on each M-G set and the M-G sets are started on only 30% of their rated kva. As an M-G set reaches 80–90% of synchronous speed, inductors on the 4,160-volt feed short out and full voltage is applied with little power-transmission interference; at this point the auxiliary pumps shut off automatically. Startup of the M-G sets by motorizing the d-c generators, followed by closing the a-c feed breaker on the a-c motors, was considered, but it was rejected because it would cost more to install and maintain and be more complex to operate.

A common external source excites the fields of both generators. Provision is included for automatic load division between the M-G sets to ensure simultaneous parallel operation, which keeps one generator from motorizing the other and causing equipment failure. A stable d-c power supply is mandatory for successful heat-transfer experiments.

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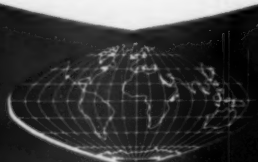

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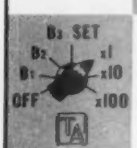

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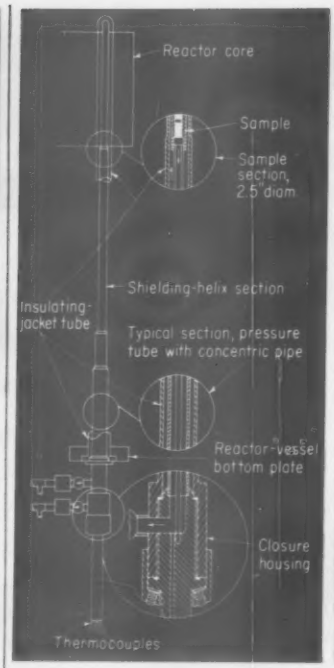

FIG. 1. FOR WTR, to avoid passing piping for the seven thimbles through the upper tank structure, thimbles are of reentrant type in which fluid enters pressure housing via central pipe and returns via annular channel. Assembly shown is 18 ft high

Designing High-Pressure In-pile Test Thimbles

By MAX A. VOGEL
Westinghouse Electric Corp., Pittsburgh, Pa.

In-pile pressure tubes, or "test thimbles," provide extremely useful means of duplicating a variety of environments for testing specimens of reactor construction materials in test reactors. Thimbles of two different types have been designed for use in the Westinghouse Testing Reactor (Fig. 1) and in the Materials Testing Reactor (Fig. 2). Both thimbles are designed to operate at 2,000 psi and 600° F. Factors in their design illustrate that an in-pile tube is actually a reactor vessel in miniature.

The prime considerations applying to in-pile-tube design are general shape and mechanical design, material selection, pressure and thermal stresses, ASME code considerations, hydraulics and heat transfer and shielding.

General Shape and Design

To obtain maximum neutron flux in a test thimble, it must be in or close to the reactor core. Thus thimble design, size and shape tie in closely with the test-reactor design.

The seven WTR thimbles pass entirely through the reactor core. One is in the center of the core and six are 60 deg apart 11 in. from the center of the core (but within the core barrel). They are 2.5 in. in diameter, which makes them interchangeable with fuel assemblies. WTR control rods, fuel elements and other mechanical devices enter from the top; the thimbles are inserted from the bottom. To avoid extending thimble piping through the upper tank structure, the WTR thimbles are of the reentrant type, as shown in Fig. 1. The advantages of this arrangement over a through-type thimble are ease of changing experiments, short connecting piping, small shielding requirements and high fluid velocities; the only disadvantages are the slightly greater design complexity and the relatively high pressure losses for a given flow.

Since the WTR thimbles are intended for very diverse experimental

use, an autoclave-type high-pressure closure and a machine for remotely handling the thimbles allows periodic insertion and removal of specimens.

For any type of thimble, allowance generally must be made for differences in thermal expansion between the high-temperature pressure pipe and the cooler insulating jacket. This can be accomplished with mechanical clearances or expansion joints in the jacket piping. Where possible, expansion joints should be avoided inside the reactor vessel as they are potential sources of leakage. Stress concentration, which might cause fatigue cracking, should be avoided by having no abrupt metal changes.

MTR. Design of the MTR thimble was determined largely by the location available within the reactor tank and by the nature of the materials to be tested (Fig. 2).

Material Selection

The ideal in-pile thimble material should have high ultimate tensile strength, high creep strength, high fatigue strength, high ductility after irradiation, low thermal expansivity, high thermal conductivity, small capture cross section for neutrons and low cost and should be easy to fabricate.

No one material has all these features; so the best compromise must be reached. Zirconium alloy and the martensitic 400-series and the austenitic 300-series stainless steels appear to be the most promising materials, depending on specific application.

Zirconium alloy. Zr is best from a nuclear standpoint because it has a very small neutron-absorption cross section; it also has excellent corrosion resistance and fair mechanical properties. Its chief disadvantages are its high cost and the fact that the ASME codes have not recognized it as a material for pressure vessels.

Stainless steels. Despite their higher neutron absorption, the 400-series stainless steels offer many desirable properties. Their thermal conductivity is greater and their thermal expansivity is lower than those of the 300-series stainless steels; thus for a given amount of gamma heating, the thermal stress of the 400-type is considerably lower. Also, the 400-series can be heat-treated to increase yield and ultimate strength appreciably without too much loss of ductility, and they are somewhat less subject to stress corrosion in halide-containing environ-

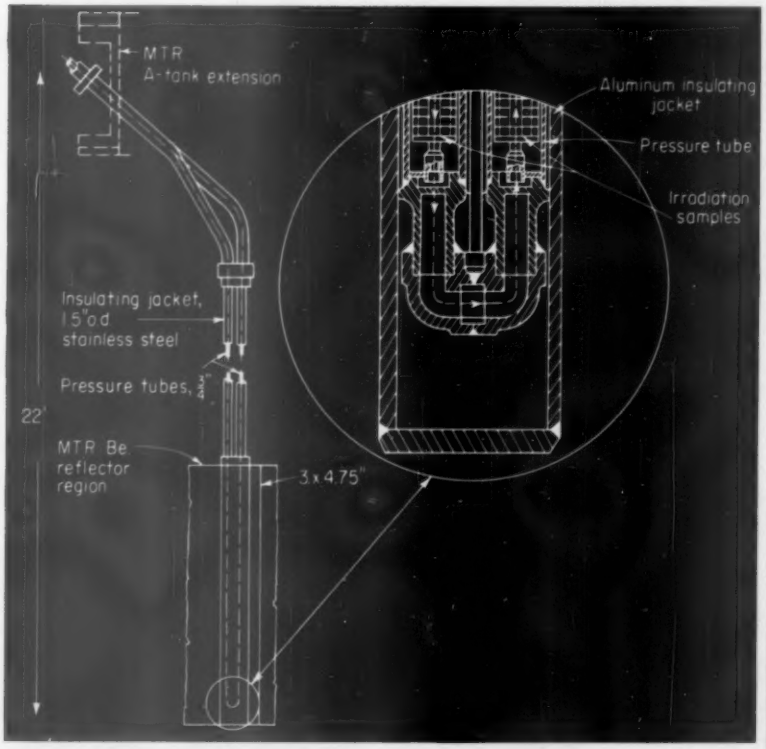

FIG. 2. MTR THIMBLE, for testing materials for reactor for Yankee Atomic Electric Co., is a U-tube return-bend unit that is inserted in MTR reflector. Piping enters via nozzles near top of MTR vessel. Since materials studies are of prooftest type, specimens are seal-welded into thimble, which gives leaktight inexpensive closure

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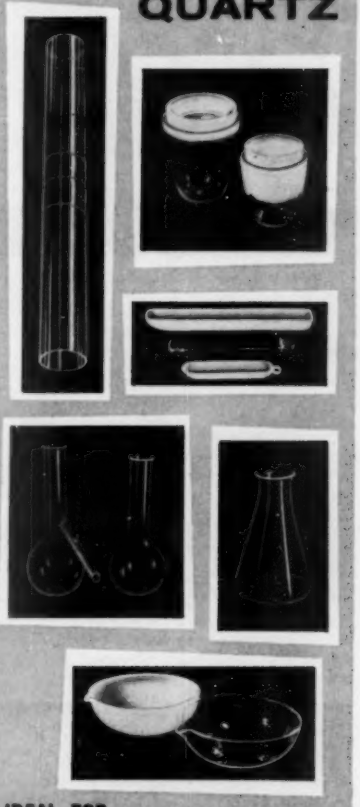

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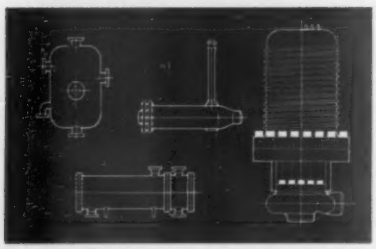

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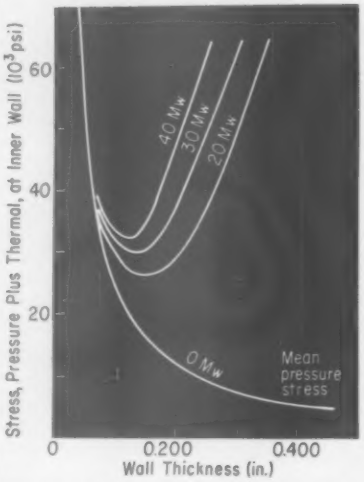

FIG. 3. PRESSURE-PLUS-THERMAL stress vs. wall thickness of ss-316 in-pile thimble having 2.5 in. o.d. at 2,000 psi internal pressure, at various reactor powers. WTR thimble wall is 0.165 in.; at 20 Mw gamma heating is 6.3 watts/gm of stainless, pressure stress is 14,400 psi and combined stress is 26,500 psi

ments. But since great care usually is exercised in cleaning in-pile thimbles and in maintaining proper loop chemistry, their lesser tendency toward stress corrosion does not warrant the use of the 400-series over the 300-series.

The chief objections to the use of the 400-series now are: (a) the ASME codes do not recognize increased strength produced by heat treatment, and (b) their rate of insoluble-corrosion-product formation in reactor environments appears to be greater than that of the 300-series stainless steels. This explains why practically all existing in-pile thimbles are of 300-series stainless steel even though they have relatively high neutron absorption and a higher thermal-stress coefficient.

Of the 300-series, types 304, 316 and 347 are most representative of the characteristic differences of various grades of austenitic stainless steels and are the ones used most often. All three have the same thermal-stress characteristics. Their prime differences are their resistance to intergranular corrosion when sensitized and their mechanical strength. Type 304 stainless steel has given excellent service at the MTR as long as chemical decontaminants or active gaseous atmospheres have not contacted in-pile tubes. Where it is necessary to decontaminate a loop periodically, it is desirable to replace 304 stainless steel with the stabilized 347 type.

Type 316 stainless steel has the same corrosion characteristics as 304 at in-pile-thimble operating temperatures. The chief advantages of type 316 are that it possesses the highest allowable code design stress, the highest stress to rupture at temperatures of 1,000° F and the highest fatigue strength and lowest creep rate of any of the 300-series stainless steels. These properties allow the use of considerably thinner walls for holding the internal pressure. Since in-pile tubes in high-flux reactors probably will have to be replaced because of radiation damage long before chemical sensitization occurs, type 316 is the most logical material despite its somewhat lesser resistance against carbide precipitation and intergranular corrosion.

Choice of in-pile-thimble insulating-jacket material is relatively easy. Because of the lower pressures and temperatures here, aluminum serves the purpose ideally. The slightly lower neutron absorption of zirconium as compared with aluminum does not warrant its use because of the high cost.

Pressure, Thermal Stresses

To simulate today's water-moderated reactors, in-pile thimbles must withstand mechanical stresses from internal fluid pressures of 2,000–2,500 psi. Thimbles also are subject to thermal stresses caused by gamma heating of the tube metal wall. Generally it is desirable to insulate the pressure tube thermally from its surroundings; thus the gamma heat must flow from the outside of the pressure tube to the fluid being circulated through the tube. This results in a temperature gradient across the wall which induces differential-expansion stresses. Thermal stresses induced in a 2.5-in.-diameter 316-stainless-steel tube are not very significant at gamma-heating rates of 1 watt/gm of metal but become appreciable at 15 watts/gm.

By using appropriate heat-transfer and stress-analysis relations, it is shown that thermal stress peaks at the inside of the tube wall and is

$$\frac{EH\alpha\, d^2}{8k(1-\mu)}\left(\frac{2\beta^2 \ln \beta}{\beta^2-1} - \frac{3\beta^2-1}{2\beta^2}\right)$$

where E = Young's modulus, psi; H = heat-generation rate, watts/in.^{3}; α = coefficient of thermal expansion,

in./in./° F; d = outside diameter of tube, in.; k = thermal conductivity of metal, (watts/in.²)/(° F/in.); μ = Poisson's ratio; and $\beta = d/(d - 2t)$, where t = wall thickness, in.

High internal pressures can be provided for by increasing the tube-wall thickness to reduce pressure stresses; but this increases the thermal stress. The combined stress, pressure plus thermal, is a minimum at some wall thickness for set values of E, H, α, d, k, and μ. Figure 3 shows an example.

Since local stresses in excess of the proportional limit are relieved by plastic flow of metal, it is possible that peak combined stress should not be a design criterion.* But plastic flow results in permanent strains in the tube material. As the long-term effects of nuclear radiation on metal properties are uncertain, it seems prudent to limit combined stresses to the value of the yield strength at the expected maximum metal temperature. Unfortunately, the ASME codes make no provisions for thermal stresses and, in effect, allow any wall thickness required to limit internal pressure stress to safe values.

ASME Code Considerations

Since in-pile thimbles usually are of such small volume and of such application that they fall under the jurisdiction of the piping code rather than either the fired- or the unfired-pressure-vessel code, it has become practice at the MTR to design in-pile tubes according to the ASME code for pressure piping. But the in-pile tube is used neither just as a pipe for conveying fluid nor as a "fired" vessel in the steam-boiler sense. Since heat-producing fissioning material might be contained by the tube without having any external heating source (resulting from the combustion of fuel) applied to it, the ASME code for unfired pressure vessels appears to be the most applicable one.

As designed, the thimbles meet the fired, unfired, and piping codes (*7–9*)—

* This has been confirmed by theoretical and experimental work published after the thimbles were designed (*10*); alternating thermal stresses might far exceed the yield point of the structural material without failure. It is planned to operate the WTR test thimbles at a combined stress of over 50,000 psi (a thermal stress of 36,000 psi when operating at 60 Mw). But this does not invalidate the concept of attempting to minimize stresses by optimising wall thickness; it does mean that one can safely operate larger diameter, thicker-walled thimbles than were thought at the time of designing these thimbles.

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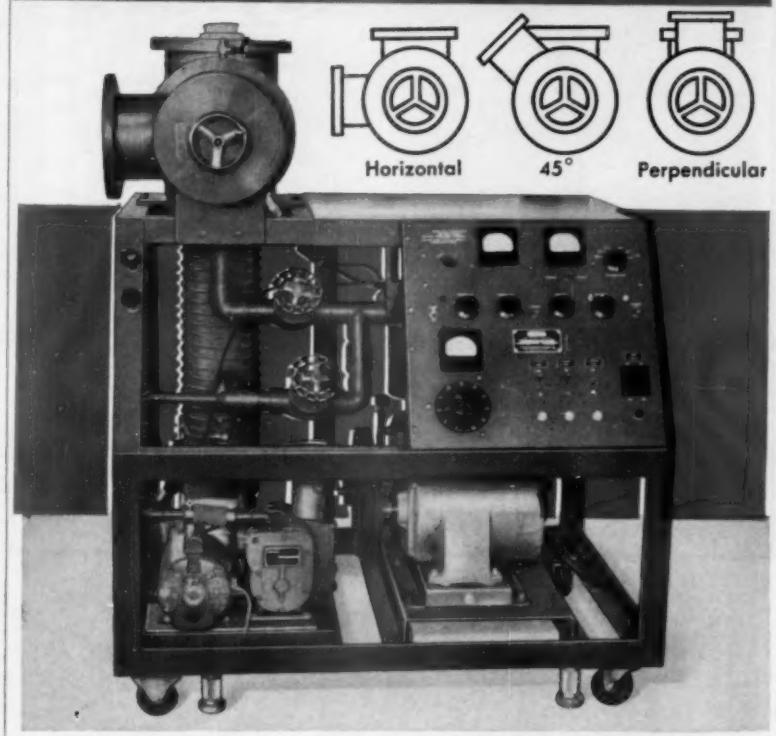

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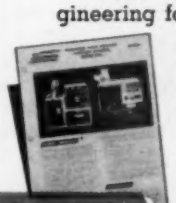

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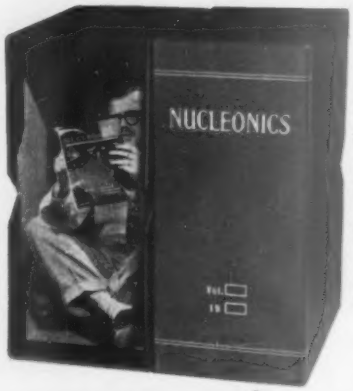

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This article starts on page 116

except for stress relief and corrosion allowance, for which an exception was granted by the State of Pennsylvania.

In any event, radiation damage presently limits in-pile-tube service life to an integrated fast-flux exposure of 2.6×10^{21} nvt; at a fast flux of 1×10^{14} n/cm²/sec this corresponds to a service life of about 10 continuous-exposure months—or, with normal reactor downtime, 13–15 calendar months.

Hydraulics, Heat Transfer

To cover the range of present core fluid velocities, in-pile tubes must be designed so that 10–40 ft/sec can be attained past sample specimens. High fluid velocities are particularly important for fuel-element testing because the "burnout" heat flux of fuel elements is proportional to the square root of the velocity—to double the burnout heat flux, velocity must be quadrupled. (The burnout heat flux is that heat flux above which the heat-transfer fluid cannot absorb heat as fast as it is generated by the fuel element.) It is desirable to keep the peak operating heat flux of a fuel element at least a factor of two below the burnout heat flux. High velocities require small fluid passages in the vicinity of the test sample.

To compensate for the high pressure losses through the test samples, flow channels leading to and away from the test specimens should be relatively large. Figure 1 illustrates how this principle is carried out in the WTR thimble.

Since high-pressure high-temperature in-pile tubes usually are immersed in low-pressure low-temperature reactor water, it is desirable to surround them with an insulating jacket that prevents excessive thermal stresses across the in-pile tube wall, boiling inside the reactor water and excessive heat losses from the test loop during reactor shutdown periods. The insulating jacket must limit heat losses to the reactor water to low values. The simplest method is to maintain an air gap between tube and jacket; better insulation is obtained by maintaining vacuum in the insulating gap. The thimble for MTR is designed in this manner.

Shielding

Inlet and outlet flow passages of in-pile pressure tubes are also good

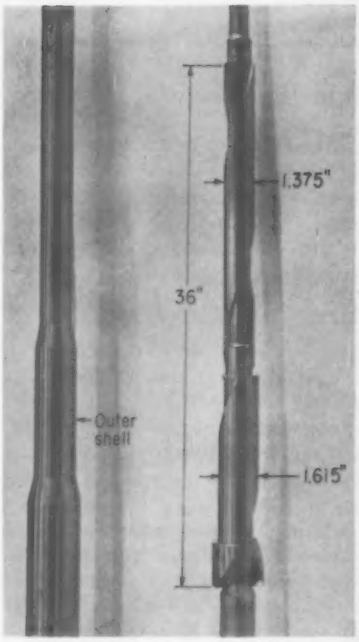

FIG. 4. HELICAL SLOT in WTR thimble pipe shields radiation while permitting fluid flow. Slot has 18 in. pitch; for every 3 ft of bar there is 2 ft of shielding, which corresponds to that of WTR pressure vessel

radiation paths. If there is sufficient length of water between the test section and the exit point, no additional shielding is required. But generally the biological shielding of a reactor vessel is greatly reduced where pipes pierce its shell. For WTR, this is compensated for by the helical stainless-steel bars shown in Fig. 4, which are inserted into the flow passages of the WTR in-pile tubes. This arrangement provides maximum shielding with minimum fluid-pressure loss.

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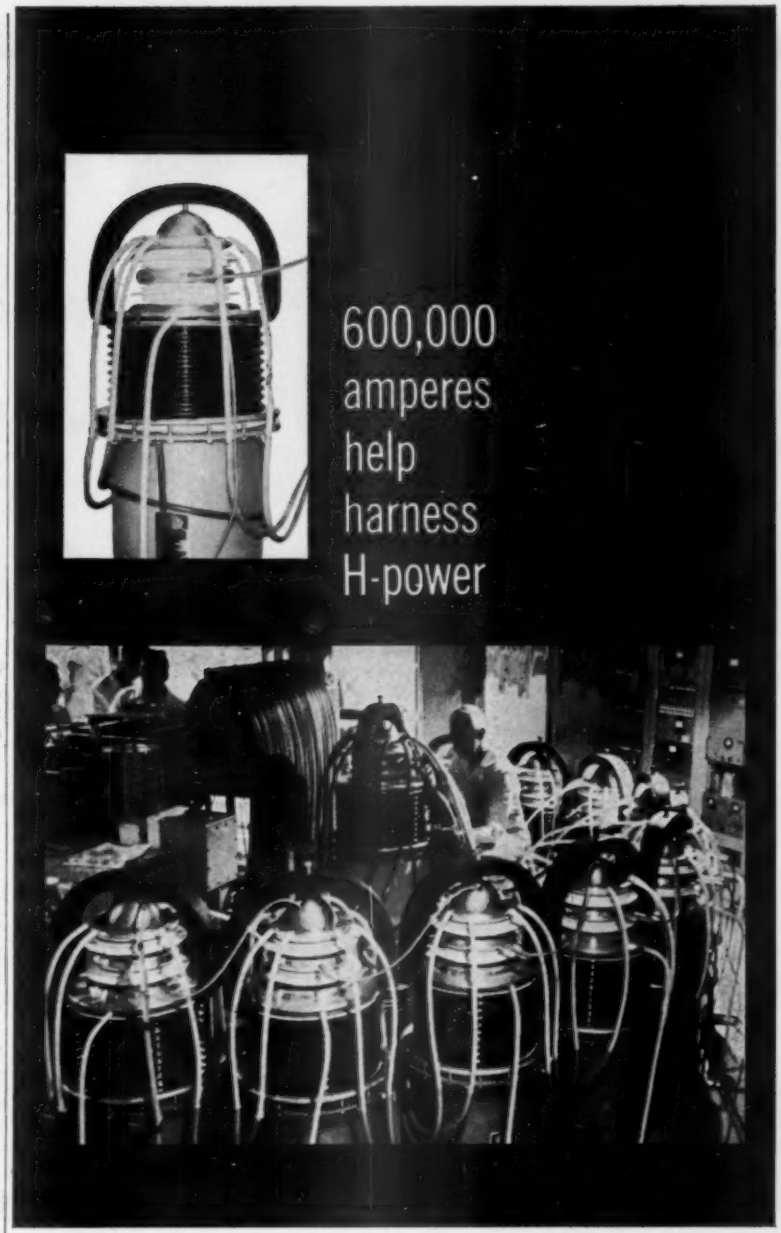

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FIG. 1. IRRADIATED POLYETHYLENE FOOD WRAPPING has gloss, transparency, strength and large shrink energy. Heat sealing below paper container and shrinking with hot air make a pear package that admits air at ends but prevents bruising

Irradiation Is Producing Food Wrapping at 10^6 lb/yr

Irradiation technology has put on display its first large-quantity product that can obviously hold its own in a competitive market. The product is L Film, a heat shrinkable polyethylene food wrapping made and marketed by the Cryovac Division of the W. R. Grace Co. Cryovac has been selling the film for more than a year (NUCLEONICS WEEK, Jan. 28 and Mar. 24), is producing it at about a million pounds a year, can now produce at double that rate and is doubling its present production capacity. The film is made at Simpsonville, N. C., where the company has an estimated five to seven GE resonant-transformers (2-Mev, 10 kw each) with a total radiation output of 50–70 kw.

Without government subsidy Cryovac has developed a film that appears to be better than the ones that cost the same, cheaper than the ones with the same performance and unique in many of its most useful properties.

The film production is the first radiation process to combine large-volume production and obvious commercial advantage, although it is not the first commercial use of radiation. Other radiation processes now appear to be meeting competition after early days of struggle. Radiation sterilization of sutures at Ethicon, once said to be a bit more expensive than heat sterilization (NU, Mar. 59, p. 86), is currently about equal in cost or a little cheaper. Makers of irradiated polyethylene wire insulation are trying hard to meet the difficult specifications of military and space applications. Raychem Corp. of Redwood City, Calif., which now has an installed 28 kw of radiation power and 90% of the market for irradiated polyethylene, is in the midst of a 400% expansion and will introduce new products at about one per month during the coming year. Its current annual sales are $>\$2 \times 10^6$.

Economics of L Film

Present selling price of the Cryovac L Film is 3¢/1,000 in². The manufacturer makes it plain that demand sets the price, not production cost; it is priced to compete with similar films but could sell for less and still make a profit. Comparable films and their prices per thousand square inches are Videne, 4.36¢; Saran, 4¢; Reynolon, 3.3¢; Cellophane, 2.7–3.3¢; and ordinary polyethylene, 2.7¢. Principal advantages of L Film are clarity (see Fig. 1), gloss, strength, large shrink energy, printability, permeability to oxygen (it is a "breathing" film) and adaptability to automatic packaging machinery.

Production Method

To make L Film Cryovac extrudes polyethylene into a tape, irradiates it in a single pass under a General Electric 2-Mev resonant transformer and then stretches it in two directions (Fig. 2). This is about all the company engineers are willing to tell about their process.

It is not clear that there are no additives in the extruded tape or whether substances are added after irradiation. On the other hand, there are distinct implications that for food-wrapping considerations the film can be treated just like unirradiated polyethylene; one can infer that there

Characteristics of L Film and Unirradiated Low-Density Polyethylene

Characteristic	*Irradiated L film*	*Low-density polyethylene*
Cost (¢/1,000 in²)	3.0	2.7
Tensile strength (10^3 psi)	8–10	1.3–2.5
Elongation (%)	60–90	50–600
Bursting strength (Mullen—psi)	35–45	48
Tearing strength (Elmendorf—gm/mil)	10–15	150–350
Heat-sealing range (°F)	300–500	250–350
Water absorption, 24-hr immersion	0	0
Water-vapor permeability (gm/100 in²/24 hr at 100° F, 90% relative humidity)	0.6–0.7	1.2
Oxygen permeability, 1-mil film (10^3 cm³/100 ft²/24 hr)	7–8	
Maximum use temperature (°F)	220	180
Minimum use temperature (°F)	−60	−60

FIG. 2. MANUFACTURING PROCESS. Film at right passes down into irradiation pit, under GE resonant transformer (dome at left) and then to stretching process

are no additives—or at most only a small quantity.

The stretching method is also a carefully concealed company secret. Cryovac refers to the stretch as "100% or more," but observations of printed films before and after shrinking convince some that the stretch is by a factor of about four in both directions; an increase in area, that is, by a factor of ~16. The product is available in thicknesses between 0.5 and 2 mils.

Radiation dose is not revealed, nor are various numbers from which one might compute it: beam power, thickness of tape before stretching, speed under beam. It is generally recognized that crosslinking of polyethylene requires $1\text{–}2 \times 10^7$ rads. Perhaps additives can reduce the requirement; perhaps Cryovac has found the additives; perhaps they can settle for less than maximal crosslinking.

Why radiation? In spite of uncertainties, however, it is quite certain that radiation is solving many problems for Cryovac. The company set out to supplement its line of heavy, impermeable polyvinylidine-chloride shrinkable films with an inexpensive, good looking, breathing film appropriate for fresh meats, fruits, vegetables and bakery products. Ordinary polyethylene offers small cost, but it is dull and cloudy, and when you stretch it, it breaks. Chemicals that might crosslink it produce more problems than they solve; in particular they are likely to migrate into food. Radiation crosslinks the polyethylene so that it can be stretched (biaxially oriented) and at the same time makes a trans-

radiation energy

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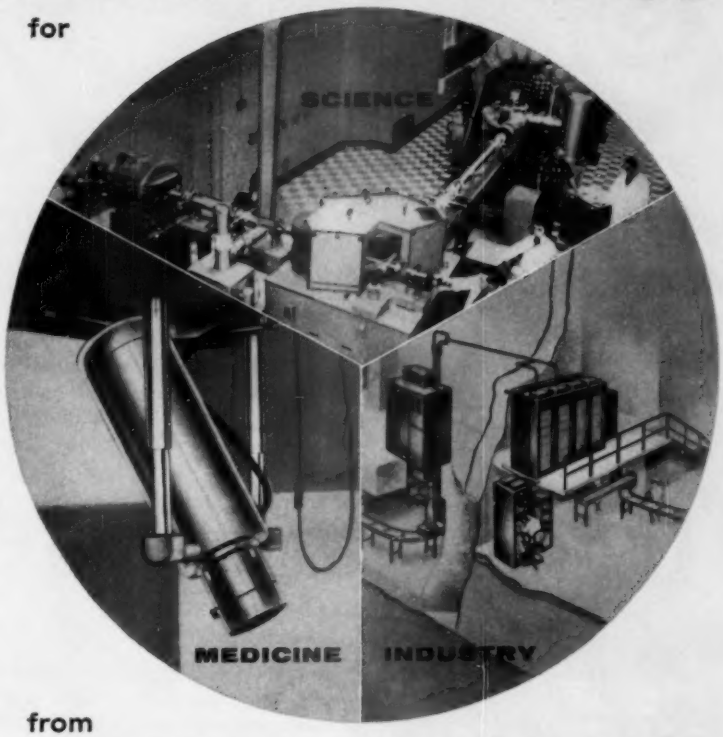

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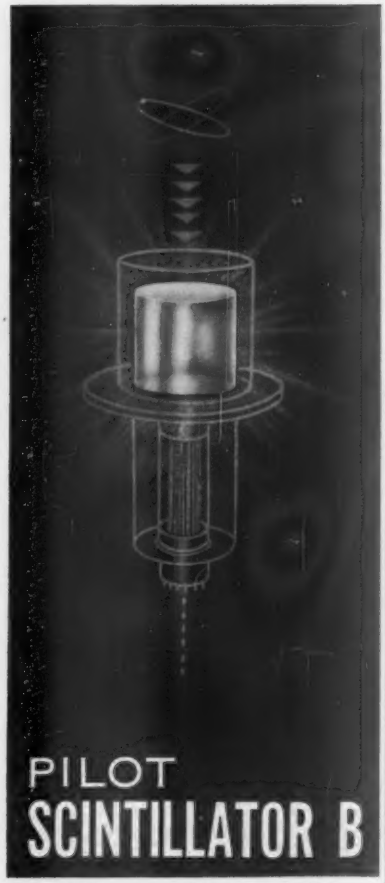

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*U.S. PATENT #2,710,284

parent, glossy material from the originally dull and cloudy polyethylene.

Packaging Use

For the designer of packaging machinery the outstanding property of the film is its shrink energy. The basic wrapping process is as follows: overwrap the package with L Film, seal the film where it overlaps by running it over a hot plate, cool the seal by running over a cold plate, run the package through a shrinking tunnel in which hot air (300°–500° F) causes the film to shrink around the package.

The package in Fig. 1 is an example. Here the film remains open at the ends for air circulation, and the tension keeps the fruit from moving. In other applications a skin-tight wrap is applied. For bakery products one can shrink the film around the lip of an aluminum-foil pan.

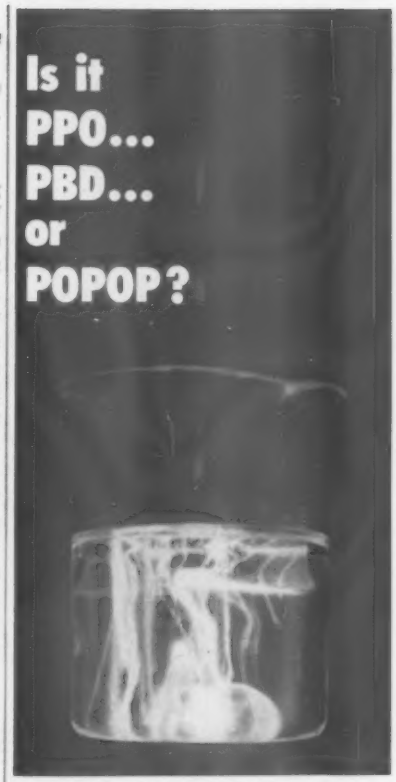
Safety and the Law

For more than two years Cryovac has been conducting animal-feeding tests, migration analyses and extractions in cooperation with the U. S. and foreign governments. The tests show no difference between irradiated and unirradiated polyethylene.

To the two government agencies involved, the Meat Inspection Division of the Department of Agriculture and the Food and Drug Administration of the Department of Health, Education and Welfare, there is no difference either. Unlike radiation applied directly to food, the irradiated film requires no special sanction as long as one can demonstrate an absence of induced radioactivity in the film. The 2-Mev accelerator energy is well below that required to induce radioactivity in polyethylene.

In the current turbulence of the new food laws and their interpretations, polyethylene has a "prior sanction" for aqueous foods and a one-year extension in which the food industry can use it in contact with fatty foods and demonstrate its innocence.

More than 175 meat and poultry packers are now using L Film; they include Swift, Armour, Wilson and Safeway. Some have asked the manufacturer whether the film is irradiated and then accepted it after talking with the government agencies. Others have simply accepted the film after hearing that the government raises no objections to its use.



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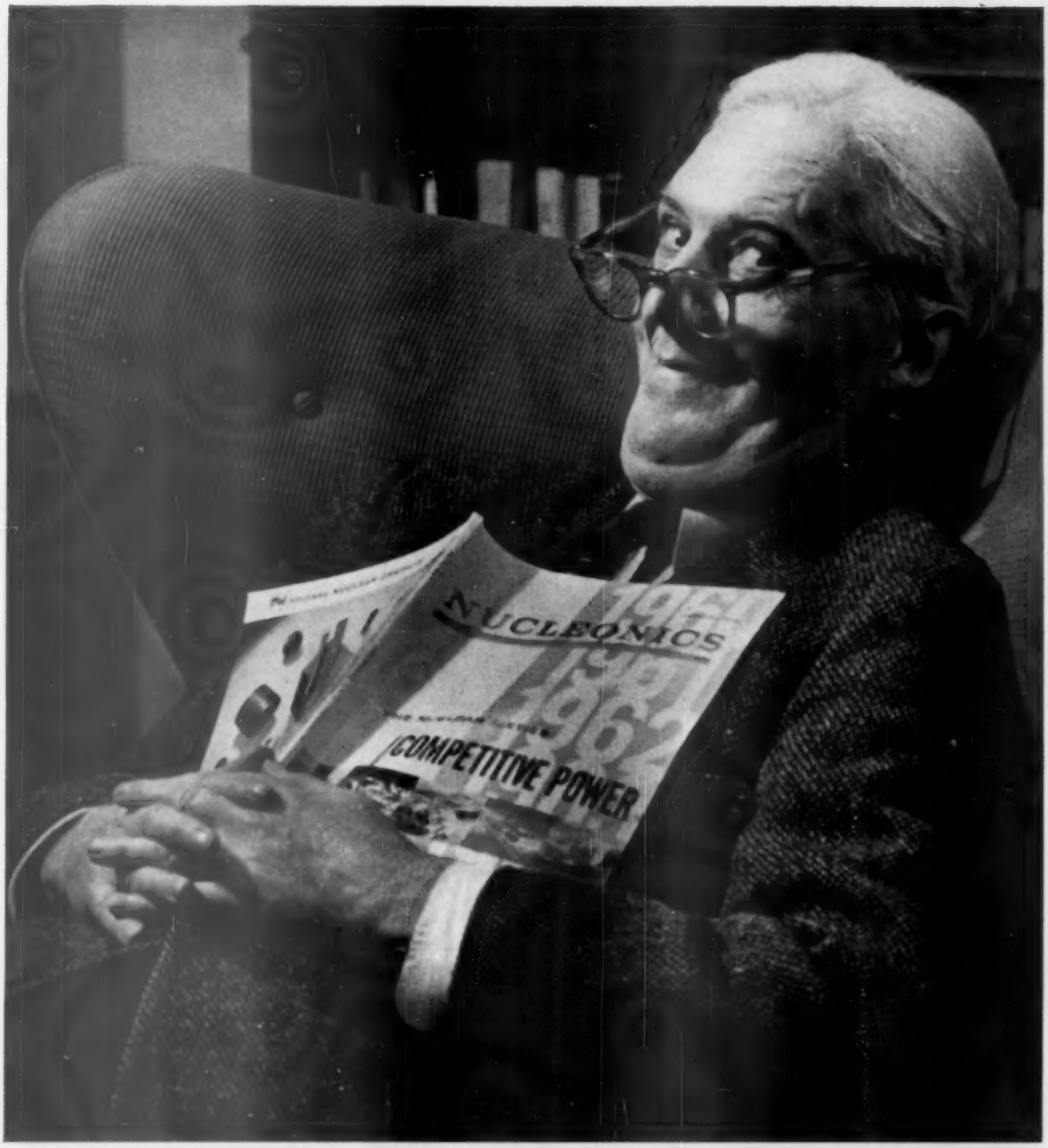

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FIG. 1. IRRADIATION PIT of University of Florida 6,000-curie facility. Above source-storage tank is concrete lid for reducing radiation scattering by air

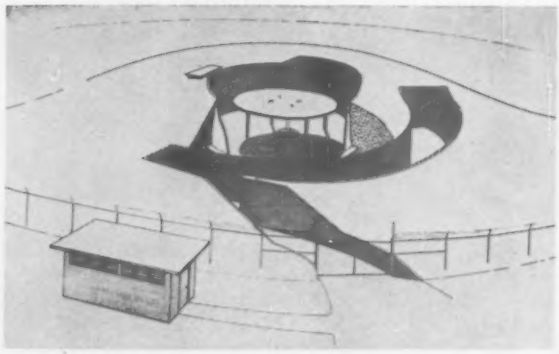

FIG. 2. LARGE-SOURCE FACILITY is approached by below-ground-level driveway. Operating shelter has 8-in.-thick concrete walls and 4-in.-thick roof

Versatile Gamma Facilities at the University of Florida

By J. M. DUNCAN, R. K. STOCK, J. A. WETHINGTON, Jr. and H. J. TEAS
University of Florida, Gainesville, Florida

Two relatively low-cost Co^{60} irradiators at the University of Florida are used for a variety of experiments. One is an 800-curie source in the College of Engineering for irradiation of small biological and chemical samples; the other is a 6,000-curie open-air irradiator at the Agricultural Experiment Station for living materials.

6,000-CURIE IRRADIATOR

The Agricultural Experiment Station facility provides a wide range of radiation dose rates so that experimenters can apply (1) low doses for genetic effects, (2) medium (10,000–200,000 r) in moderate exposure times for food pasteurization, production of physiological changes and pest control in food and feed products and (3) large doses (2–3-million r) in a few hours for pasteurization and sterilization of food and feed items as large as a small ham and for chemical studies of radiation effects on agricultural products.

The facility (Figs. 1 and 2) is on a 5-acre fenced site on the university farm, about one mile from the main campus at Gainesville.

Design of Facility

The radiation pit, 30 ft in diameter and 12 ft deep, is constructed of reinforced, normal-density concrete. A 12-in.-thick concrete lid over the source, supported by four posts, reduces backscatter from the air ("skyshine" radiation). Measurements made before the lid was installed indicated the necessity for this additional shielding. A driveway 12 ft wide and 12 ft deep with a switchback (Fig. 2) leads from the radiation pit; a portion of the driveway is covered with earth and concrete to prevent the escape of low-angle radiation.

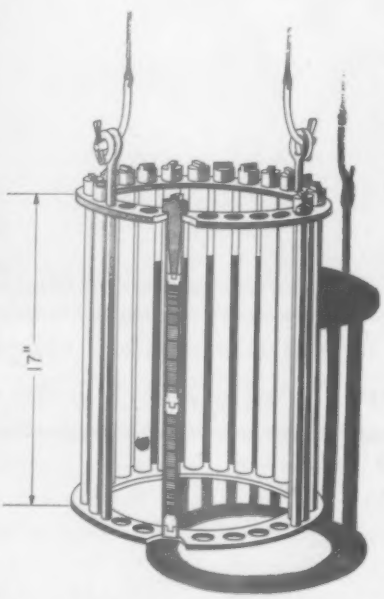

FIG. 3. COBALT SOURCE is in stainless-steel structure. Only 12 of 24 tubes are at present loaded with cobalt. Aluminum spacers contribute to field uniformity

The source (Fig. 3) is a cylinder that provides a relatively uniform radiation field inside and an external field as well. It is arranged to make possible extended irradiations of potted plants in daylight and also large specimens such as fairly large trees and cattle.

Water tank for source storage. A 2-ft-i.d. water tank in the center of the radiation pit is for source storage when the source is not in use. A larger tank (3 ft 6 in. i.d.) near the side of the radiation pit was used to load the irradiator and provides storage for other sources. Both tanks are 13 ft deep and are connected by a canal 5 ft deep and 1 ft wide. A continuous welded-steel envelope served as an outer form for construction of the concrete tanks and canal. The tanks and canal are provided with locked steel covers, indicated in Fig. 2.

Source elevator. The source is raised and lowered at 1 ft/sec by two

stainless-steel cables. The motor is in a concrete housing outside the radiation pit. A follower on the cable operates micro switches to position the source at its upper (fully exposed) and lower (stored) positions. An adjustable stopping switch can also be set to stop the irradiator at any intermediate position.

Colored panel lights in the operating house indicate the source position by two means. First, the cable follower operates switches that activate lights to show "safe," "unsafe" and "unsafe, completely up" source positions. Second, an electronic radiation alarm (Brookhaven National Laboratory Model EHI-545-1-4C) outside the radiation pit indicates "safe" and "danger." The alarm is set for a threshold radiation level to show when the source begins to emerge from the water.

Safety devices. Several safety devices minimize the risk of accidental personnel exposure:

1. A steel cover can be locked in place over the operating switch. Each worker who enters the circular fenced area locks the switch cover and takes the key with him.
2. Red and green lights in the driveway and radiation pit indicate "safe" or "unsafe."
3. The radiation alarm operates four flashing red lights and a loud horn when radiation is above a threshold level.
4. A battery-powered buzzer in the operating house indicates power failure.
5. A clutch and brake are provided on the elevator motor shaft for lowering the source in the event of a power or motor failure.
6. A solenoid interlock system permits the source to be raised only if the gate is closed and locked.
7. A bar is clamped onto the source-lifting cable just below the level of the steel covers on the source-storage tank before closing and locking the covers and is removed before the irradiator is raised. This bar prevents an intruder from raising the source manually to just below the tank cover.
8. An emergency release drops the source into the water tank (Fig. 4).

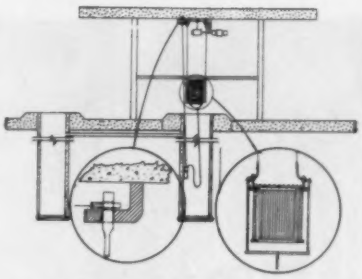

FIG. 4. **EMERGENCY RELEASE** drops source from exposed position into storage tank. To do this, manually operated cable pulls pin from rod supporting 50-lb lead weight. Weight drops, pulling on yoke hanging below source, which removes cotter pins from cable-to-source connectors. Inserts in circles show release-pin assembly (left) and source

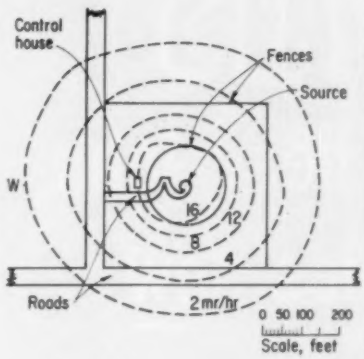

FIG. 5. **ISODOSE LINES** around 6,000-curie source show radiation levels due to "skyshine" after installation of concrete lid over source (measured in March, 1958)

Radiation Levels

Radiation levels were measured by three means: a Victoreen ratemeter with four overlapping chambers, a Landsverk r-meter and ferrous-ferric dosimetry. All dose measurements are corrected to November, 1958, when total activity was ~5,900 curies.

Within the source. Irradiation of materials within the source is made easy by a cylindrical metal can 8 in. in diameter and 21 in. high supported so that the source is raised around it. The radiation flux has a maximum variation of 1.4% over the central 8 in. of the can axis. Dose rate in the center of the cylinder was 2.8×10^5 r/hr (November, 1958).

In the radiation pit. Doses with the source up are shown in the table. An

Dose Rates in Radiation Pit

Distance from center of source (ft)	*Dose rate* (r/hr)*
3	8,460
5	3,260
7	1,630
9	990
11	700
13	510

* Measured with Victoreen ratemeter (November, 1958).

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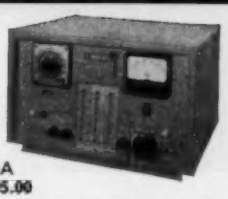

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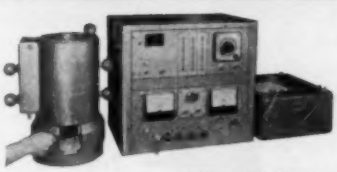

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intensity of 114 r/hr has been measured at the 13-ft circle with the adjustable stopping switch set near the lowest position.

Skyshine. Skyshine measurements were carried out with Cutie Pie survey meters before and after the concrete lid was installed as a sky shield. The data obtained after lid installation are shown in Fig. 5. Before lid installation, the radiation level at the 100-ft-radius fence was 87–120 mr/hr. After lid installation, the corresponding level was 12.5–14.5 mr/hr. Workers remaining in the operating house are exposed to <0.5 mr/hr when the irradiator is in use.

Radiation levels over facility. Radiation measurements were made with a G-M counter from a small plane that made repeated passes over the irradiation facility with the source "up." (When the source is in the "down" or "safe" position no radiation can be measured by Cutie Pie meters within the radiation pit.) At 500 ft, the minimum altitude permitted for airplanes in this area, the maximum dose was 8 mr/hr with the source "up." It was calculated that more than 1,500 passes would be required by a slow-flying airplane for its passengers to

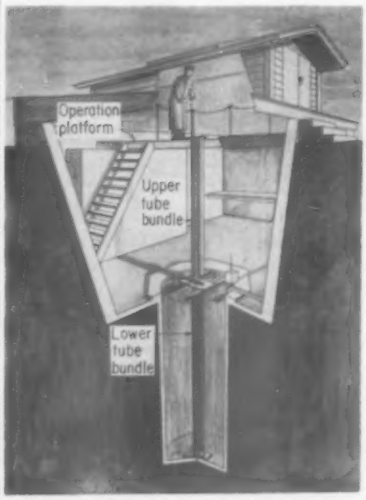

FIG. 6. COLLEGE OF ENGINEERING irradiator has source in pool below ground level. Operating platform and stairs can be removed with crane. Upper tube bundle is detachable from lower assembly to permit source loading and performing experiments at lower level. Upper tubes provide extensions of lower-assembly irradiation tubes but not of cobalt tubes; this prevents cobalt removal with upper tubes in position

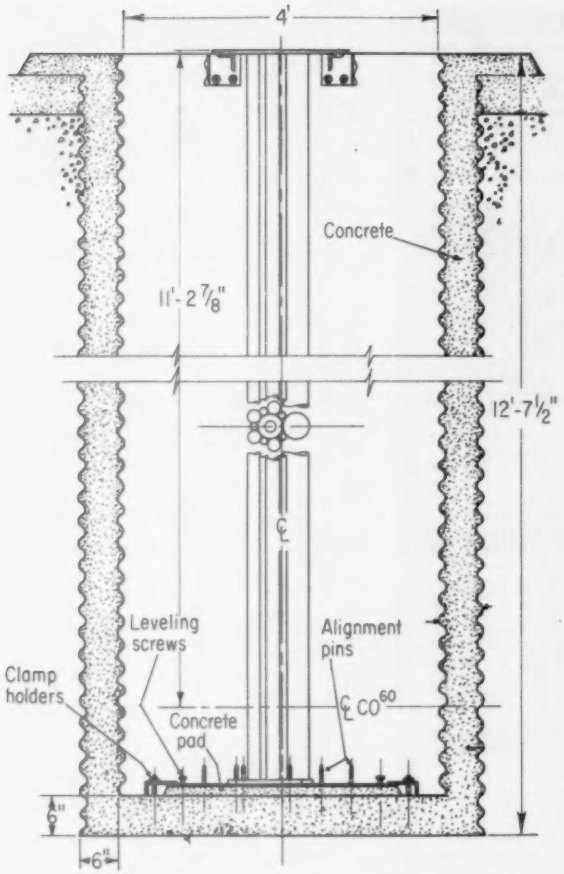

FIG. 7. LOWER ASSEMBLY of irradiator and water tank. Tank is made of concrete between 4- and 5-ft-diameter culvert pipes and 3/8-in. boiler plates at the bottom. Assembly includes source and irradiation tubes

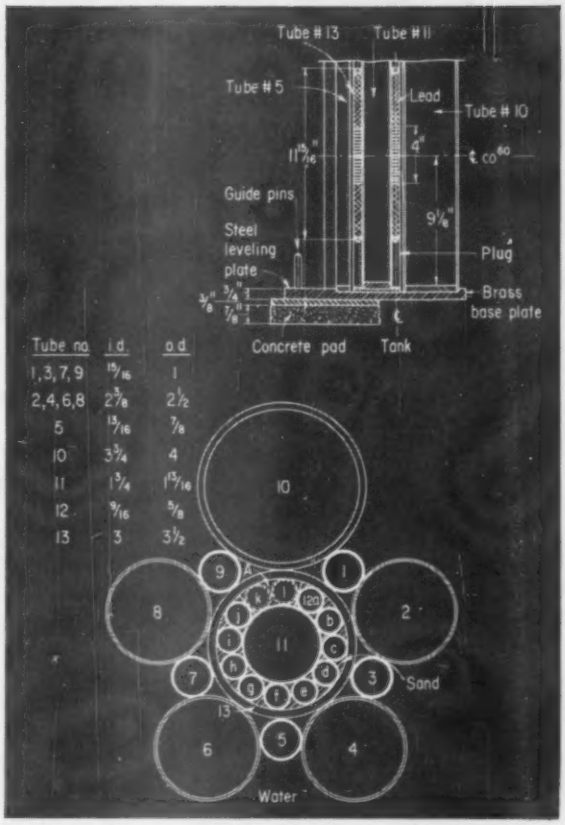

FIG. 8. LOWER-TUBE-BUNDLE cross section and details of source tubes. All tubes are brass. Tubes 12a through 12l contain cobalt; 1 through 11 are irradiation tubes; 13 is containment tube for cobalt tubes

receive a dose of 30 mr. This estimate disregards any shielding by the aircraft itself.

Applications. This multipurpose facility has proven very satisfactory for the anticipated dose requirements. It has been used for treating vegetable pollen, tomato fruit, radish, chrysanthemum, animal feed, pangola grass, ornamental shrubs, citrus, peach, control of geotropism and placental transfer in rats. It has also served for student training and laboratory exercises in nuclear engineering, chemistry and botany.

ENGINEERING FACILITY

The 800-curie irradiator was designed to be as versatile as possible at minimum cost. Source geometry was fixed by the need to facilitate Co^{60} transfer from the Oak Ridge standard shipping container for 1,000 curies of Co^{60}.

The source was placed in a pool of water since, with this arrangement, tube bundles and cobalt can be added without altering the structure. The pool is also convenient for irradiating large samples and is an adequate shield.

The building for this source was adapted from an existing, below-grade, concrete room ~10 ft deep, shown in Fig. 6. Fortunately, the roof could be removed with a crane to aid in handling the shipping container during source loading. Trap doors in the roof and working platform facilitate later additions of cobalt.

The underground tank and lower tube assembly are shown in Figs. 7 and 8. Because of the heavy-wall containment tube surrounding the cobalt cluster, three metal seals—the cobalt capsules, the cobalt-bearing tubes and the containment tube—must develop leaks for radioactivity to enter the water.

Radiation surveys were made in the vicinity of the tube bundles with a Cutie Pie. The escaping radiation is well collimated, falling to less than 0.2 mr/hr at about 50 cm from the center line of the tube bundle. Maximum readings at the floor level are 8 mr/hr with the shield plugs in the irradiation tubes and 120 mr/hr with them removed.

Dose rates measured by chemical dosimetry in the sample-irradiation zone vary widely with position. At the level of the center of the Co^{60}, dose rate varies from ~450,000 r/hr for the center tube to 57,000 r/hr for the 4-in.-diameter tube. It drops to about 50% of these values at the upper and lower ends of the cobalt region. These dose rates were measured in August, 1958.

Total cost of the facility, including labor and materials, was $8,721. Cobalt cost was $3,062; additional ORNL charges for encapsulation, loading, decay and handling totaled $915; source shipping charges were $408. Irradiator tank and tube-assembly costs were $2,615, and instrumentation was $91.

* * *

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CHEMICAL PROTECTION

(*Continued from page 81*)

Synthesized Products

Radiation-induced synthesis reactions can also be profoundly changed by protective and promoting agents. The decomposition of carbon dioxide by ionizing radiation into carbon monoxide and oxygen appears to be a useful way of storing energy to be used through combustion. These products are not formed in appreciable amounts when pure carbon dioxide gas is irradiated, however. Experimental investigation shows that carbon dioxide is not inherently radiation-resistant but that its primary decomposition products rapidly recombine to give a net yield of zero. If nitrogen dioxide gas is added before irradiation, it reacts with some of these intermediates as they are formed, and the back reaction is impeded. Subsequent reactions then produce significant yields of carbon monoxide and oxygen and regenerate the nitrogen dioxide (*87*).

An important potential use of high-energy radiation is petroleum cracking, and protective agents may enable selective conservation of certain products. A step in this direction is the report that addition of dibenzyl to irradiated *n*-heptane allows production of other normal and isomerized hydrocarbons (*88*).

The key to managing the effects of ionizing radiation is in the knowledge of how various chemical structures can modify these effects. Some information on how chemicals protect is available, but exploration in the labyrinth of possible relations has only begun.

* * *

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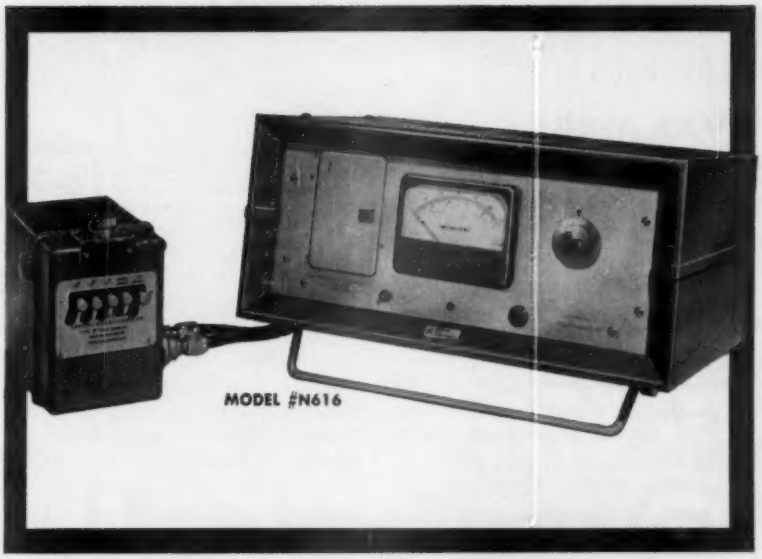

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BOOKS

Liquid-Metal Heat Transfer Media

By S. S. KUTATELADZE, V. M. BOUSHANSKII, I. I. NOVIKOV and O. S. FEDYNSKII (Translated from the Russian and published by Consultants Bureau, Inc., New York; Chapman and Hall, Ltd., London, 1959, 148 pages)

Reviewed by M. P. HEISLER, Atomics International, Canoga Park, California.

This book, which is based on Supplement No. 2 to the Soviet Journal of Atomic Energy for 1958, is devoted to problems of utilizing liquid-metal heat-transfer media in nuclear power. The book does not pretend to be an exhaustive presentation, and in this respect should not be compared to the Liquid-Metals Handbook, the Sodium-NaK Supplement, or the AEC's Reactor Handbooks. The authors have abstracted from these volumes only those data which are of the most immediate practical use to engineers who work in those fields of reactor design and nuclear power which use liquid metal as coolants.

The volume is divided into 13 chapters. Nine chapters deal with the theory and the application of liquid metal heat transfer. The first of these briefly but adequately discusses the theoretical aspects of turbulent heat transfer in liquid metals. This is followed by chapters on flow in tubes, flow around plates, transverse flow around cylinders, free convection, vapor condensation, and boiling of liquid metals. The chapters on free convection, condensation and boiling are very well done. A wealth of experimental data is presented, including most of the material developed in this country during the past ten years plus extensive experimental and analytical data obtained by the Russians. A comprehensive bibliography of the English as well as the Russian literature is cited. On the whole this is a good technical work and should be an excellent reference source for scientists and engineers who work with liquid metal coolants.

The remaining four chapters are devoted to discussing the basic properties of liquid metals, the application of liquid-metal heat transfer media, the corrosion of materials by liquid metals and the special types of instrumentation required in liquid-metal systems. With the exception of the chapter on basic properties, which presents the theory and application of the thermodynamic similarity principle to the study of the properties of liquid metals, these chapters contain very little that is new in the U. S.

The excellent technical content of the book is marred by a poor job on the part of the translators, who apparently were not familiar with heat transfer and engineering terminology. As a result the reader will find many parts of the text difficult to understand. For example, in discussing the application of baffles to heat exchangers the translators conclude that "the application of different types of partitions, serving as fortification of the tube system and as a lengthening of the path travelled by the heat transfer medium, in heat exchanging equipment complicate the choice of analytic scheme for determining the magnitudes of α_1 and α_2 with the aid of equations obtained in studying the heat exchange under the ideal conditions described above." In a number of instances, because of the double translation from English to Russian and then back again to English, the meaning of the original English text is completely lost. In some tables Russian designations for steels have not been converted over to their comparable ASTM or ASME equivalents and the tables therefore lose most of their usefulness. It is unfortunate that the translator's text apparently was not reviewed by a qualified authority prior to publication. Nevertheless, despite the fact that a poor translation makes the text difficult to understand and poor typography makes it difficult to read, the book is still a valuable and welcome addition to the technical literature on liquid-metal heat transfer.

Progress in Nuclear Energy—Law & Administration, vol. 10

Edited by HERBERT S. MARKS (Pergamon Press, New York, 1959, xii + 994 pages, $26.50)

For management people, lawyers and sales officials working with the international atom, this book is the indispensable basic reference. Herbert Marks (chairman of the Federal Bar Assn.'s atomic energy committee and former AEC general counsel) should earn their lasting gratitude for his massive work of compilation. This comfortably fat book has assembled in one place the texts of the basic atomic energy statutes, ordinances and decrees of 25 countries plus the

Euratom Treaty, the International Atomic Energy Agency Statute, and that of OEEC's European Nuclear Energy Agency; typical bilaterals, international conventions, and commentaries by experts on the state of the atom in 22 of the countries treated.

This constitutes the second part of the book; the first consists of essays on law and administration of nuclear energy. These are by acknowledged authorities in their specialties: men such as John G. Palfrey on U. S. atomic law, William Krebs on activities of state governments, Arthur W. Murphy on liability and insurance, Casper W. Ooms on patents, etc. Other articles treat of IAEA, ENEA and Euratom, the U. S. bilateral program, British atomic law and administration, and an interesting article by Philip Sporn on "Israel and the Atom: a Rational Program for Development of Nuclear-Fueled Electric Power." —*JK*

Nuclear Ship Propulsion

By HOLMES F. CROUCH (Cornell Maritime Press, Cambridge, Md., 1960, xxii + 347 pages, $10)

Dedicated "to those who design, build, operate, manage, maintain, pay for, and travel on nuclear ships," this book was written, the author says, "to enhance the understanding of nuclear ship technology." It attempts to couple two technologies in the "composite language of 'nuclear-marine,'" with necessary technical interpretation and transpositions made so that a reader with some maritime background can gain a systematic understanding of the application of this new fuel source to propulsion at sea.

The book assumes some familiarity with engineering technique, but is written for the most part in an easy style accessible to the non-technical reader. It covers among other topics fuel calculations, heat removal, shielding, refueling, "design safety" and "regulatory safety," and health physics, includes a chapter on gas reactor turbines, and another on "areas for breakthrough" (the author likes the UF_6 gas direct-feed reactor, also BF_3 gas as control material). He leans heavily on *Savannah* design for his practical examples; and properly keeps one weather eye cocked on economic effects of technical variables. —*JK*

Honeycomb, a critical assembly device, is one of many research tools developed through the cooperation of Los Alamos scientists and engineers to enhance the Laboratory's constant quest for knowledge.

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Decimal electronic switch (above) uses small rod magnets within vacuum envelope to fix position of electron beam at any one of ten output positions. Internal magnets greatly reduces size, weight, cost and power of the switch over external-magnet types. Switch has useful constant-current outputs, positive switching elements and memory in each of its ten positions. It can remain stationary indefinitely or switch at speeds exceeding 10 Mc either sequentially or at random, be interconnected as a distributor of any number of positions less or greater than 10 and be preset to any position and reset in less than a μsec. In vacuum-tube circuits, outputs up to 200 v can be obtained; in transistor systems 12-v signals can operate it. Current is available at each position to activate visual readouts, show progress of count, activate a printer or perform useful work at the end of a preset count.—Burroughs Corp., Electronic Tube Div., Plainfield, N. J.

Hinged Expansion Joints

Hinged expansion joints (above) that permit a piping system to be entirely self-supporting are used for piping systems that, because of their size or location, cannot be supported or anchored by conventional means. Bellows torsion is prevented resulting in more stable piping system. Since standard model is designed to take rotation in one plane only, these units are used in combinations of two or three.—Zallea Brothers, 815 Locust St., Wilmington 99, Del.

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Indicating transmitter for low-to-medium pressures can be located to provide pressure indication at the point of measurement or within 300 ft on an easy-to-read dial. Unit can simultaneously transmit pressure measurement electrically to remote recorder or indicator. Pressure measurement of air or noncorrosive gases ranges from 0–0.2 in. to 0–0.120 in. water and for static pressure up to 65 psig.—Hays Corp., Michigan City, Ind.

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Film scintillators with fast resolution time and ability to discriminate against gamma-rays and fast neutrons are used as fast detectors of heavy charged particles and fission fragments. Adding layer of fissionable material yields thermal-neutron detector. Film stock ranges from ½ to 5 mils thick and is 11 in. in dia.—Pilot Chemicals, Inc., 36 Pleasant St., Watertown 72, Mass.

Rubber Radium Containers

Rubber ovoids, molded from black rubber in three sizes, are used as containers for radium capsules in therapy. The center of ovoid has ¼-in.-dia hole for three quarters of its length. Sealed Pt-Ir tube containing radium sulphate is inserted there. Two ovoids locked together by molded rubber washers between them are placed in patient for three days and are then destroyed.—Dunlop Rubber Co., London, England.

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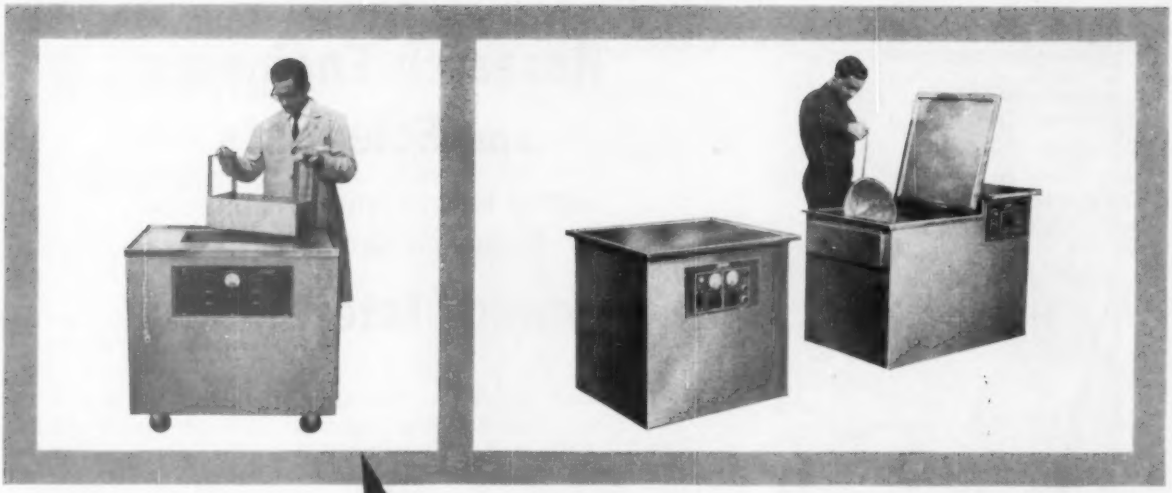

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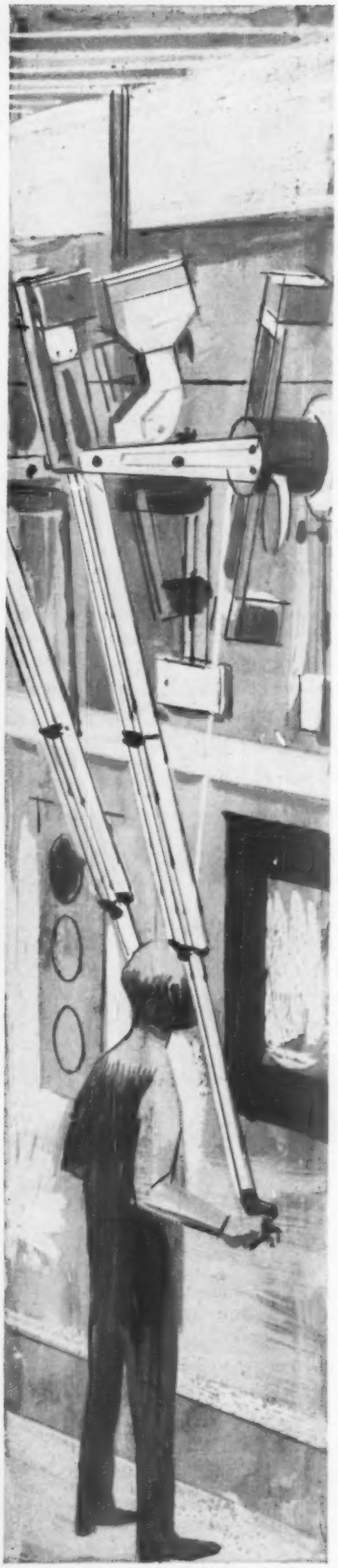

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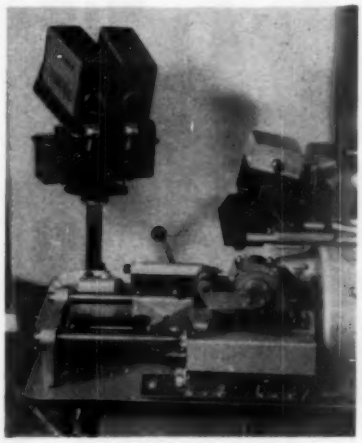
on valve stem. Piston is fixed and cylinder carries the rack.—Vacuum Research Co., 420 Market St., San Francisco 11, Calif.



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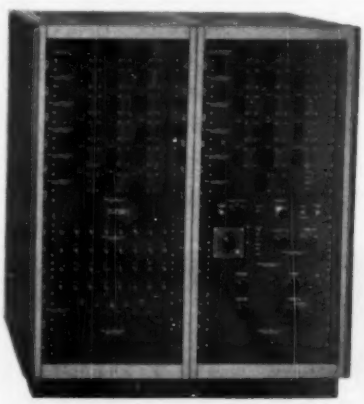

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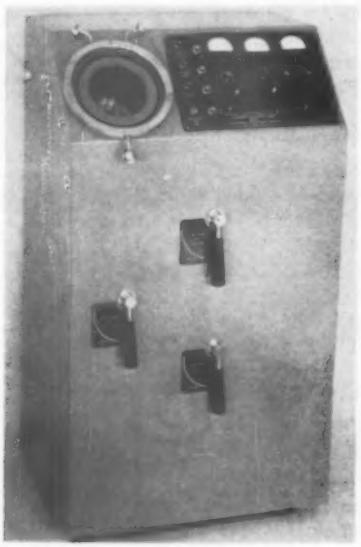

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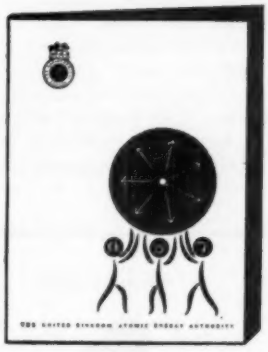

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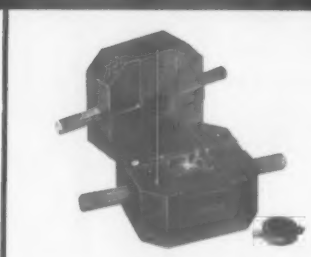

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PRODUCTS & MATERIALS

Department starts on page 134

thicknesses from ½ to 2 in. Each fitting comes in two accurately molded halves which are installed with staples, soft wire or tape.—Fibrous Glass Products, Inc., Sub. of PALL Corp., Alpa Plaza, Hicksville, L. I., N. Y.

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LITERATURE AVAILABLE

Shirt-pocket radiation alarm. 4 pp.; Gelman Instrument Co., 106 N. Main St., Chelsea, Mich.

Nuclear training system, radioisotope laboratory. Bulletin 131, 4 pp.; Nuclear-Chicago Corp., 333 E. Howard Ave., Des Plaines, Ill.

Instruments for radiation measurements. 12 pp.; Landsverk Electrometer Co., 641 Sonora Ave., Glendale 1, Calif.

Mechanical arm. 4 pp.; General Mills, Nuclear Equipment Dept., Minneapolis, Minn.

Plug valve actuator. 4 pp.; Bettis Corp., 320 S. 66th St., Houston 11, Tex.

Rotary, linear and valve actuators. 15 pp.; Jordan Controls, Inc., 3235 W. Hampton Ave., Milwaukee 9, Wis.

Automatic emergency lighting. Catalog LW-1, 8 pp.; Electric Cord Co., 432 Plane St., Newark 2, N. J.

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Alpha detector, gamma-flow detector. Data sheets 118 and 119, 4 pp.; Nuclear Enterprises Ltd., 1750 Pembina Highway, Winnipeg 9, Canada.

Electron tubes and semiconductors. Production, consumption and trade in selected European countries; 34 pp.; Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. 25 cents.

Transistor amplifiers. 2 pp.; Burr-Brown Research Corp., Box 6444, Tucson, Ariz.

Series E-100 electrometers. 2 pp.; Gyra Electronics Corp., P. O. Box 184, La Grange, Ill.

High-voltage power supply. 10 pp.; Wm. B. Johnson & Associates, Inc., P. O. Box 415, Mt. Lakes, N. J.

Servo system simulators. 6 pp.; Servo Corp. of America, 111 New South Rd., Hicksville, L. I., N. Y.

Nuclear research and process control instruments. Catalog D-100, 8 pp.; Eldorado Electronics, 2821 Tenth St., Berkeley 10, Calif.

Panel-mounting electronic voltmeters. 15 pp.; Metronix, Inc., Chesterland, Ohio.

Stainless steel tubing. 34 pp.; Allegheny Ludlum Steel Corp., Pittsburgh 22, Pa.

Aluminum tube-plate extrusions. #14, 2 pp.; Precision Extrusions, Inc., Bensenville, Ill.

Inconel heat exchanger tubing. STC-107, 3 pp.; Superior Tube Co., Norristown, Pa.

Precision tubing. 4 pp.; Damascus Tube Co., Greenville, Pa.

Vacuum-induction-melted alloys. 14 pp.; Kelsey-Hayes Co., Metals Div., New Hartford, N. Y.

Data for shielding materials. 32 pp.;

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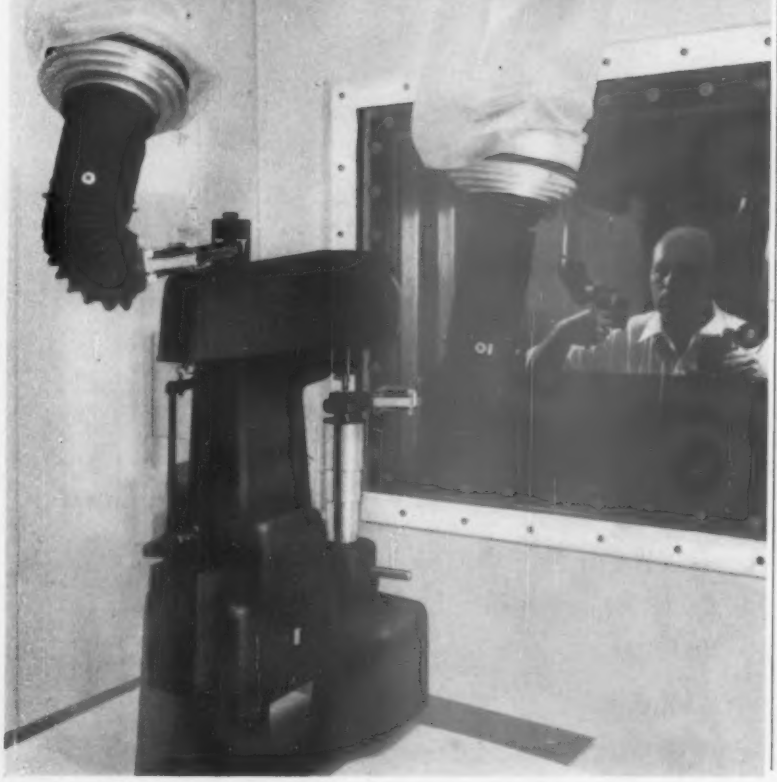

PRODUCTS & MATERIALS

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Knapp Mills Inc., 23–15 Borden Ave., Long Island City, N. Y.

Hinged closures. Bulletin TT956R, 6 pp.;
Bellows expansion joints. 24 pp.; Tube Turns, Div. of Chemetron Corp., Louisville 1, Ky.

Electronic welding equipment. 4 pp.; Weldmatic Div., Unitek Corp., 380 N. Halstead Ave., Pasadena, Calif.

Standard flexible shaft assemblies. Form 574, 8 pp.; F. W. Stewart Corp., 4311–13 Ravenswood Ave., Chicago 13, Ill.

Mechanical remote control systems. 11 pp.; Teleflex Incorporated, Nuclear Products Div., North Wales, Pa.

Controlled volume metering pump. Bulletin 1153-C, 4 pp.; Milton Roy Co., 1300 E. Mermaid Lane, Philadelphia 18, Pa.

Nuclear valves. 4 pp.; Alloy Steel Products Co., Nuclear Div., Linden, N. J.

Regulating relief valve. 2 pp.; Atlas Valve Co., 280 South St., Newark 5, N. J.

Ball valves. 4 pp.; Jamesbury Corp., Worcester, Mass.

Level, flow, pressure, temperature nuclear power controls. Consolidated Controls Corp., Durant Ave., Bethel, Conn.

Low-inductance energy-storage capacitors. Bulletin 191, 11 pp.; Cornell-Dubilier Electric Corp., S. Plainfield, N. J.

Transistor electronic computing system. 6 pp.; Royal McBee Data Processing Div., Port Chester, N. Y.

Memory tester. 4 pp.; Digital Equipment Corp., Maynard, Mass.

Computer-language translator. 20 pp.; Electronic Engineering Co., 1601 E. Chestnut Ave., Santa Ana, Calif.

High-speed printer/plotter system. 4 pp.; Briggs Associates, Inc., 10 Dekalb St., Norristown, Pa.

INDUSTRY NOTES

● **International Anti-Radiation, Ltd.,** has been established in British Columbia, Canada, to manufacture containers for disposal of radioactive wastes. The firm will also manufacture nuclear shelters. Its first order for waste containers was just under $1-million—for 1,500 high-pressure spherical vessels of 53-gal capacity for AEC wastes.

● **Charles Walsh Associates** has been named sales representative for **Instrument & Development Products Co., Inc.,** Chicago.

● **Vitro Chemical Co.** is consolidating its manufacturing activities—all chemicals will be produced at Chattanooga, Tenn., except uranium concentrates (produced at Salt Lake City). The move means shutdown of a plant at Canonsburg, Pa.

● AEC has released **80 patents** it owns for use by the public under nonexclusive, royalty-free licenses.

● Two studies for AEC on the **commercial potential of depleted uranium**—one by Battelle Memorial Institute, the other by Oak Ridge National Laboratory—show that no major market exists but that several markets have promise: metallurgical applications in special alloys, high-speed steels and high-density metals; wider application in ceramics; chemical applications in catalysis and inorganic ion-exchange systems; radiation shielding (modest use now); counterweights and ballasts (also modest use now); ammunition manufacture; cathodic protection; and use in fast-breeder reactors (*see New Business*).

● One of this country's leading radioactive waste disposal firms—**Nuclear Engineering Co.,** Walnut Creek, Calif.—has found that its customers are seeking its advice on services and equipment outside the disposal field. As a result, Nuclear Engineering says, it has entered the sales-representative field for the manufacturers of protective clothing and radiation equipment, including detection, measurement and analysis instruments.

NEW BUSINESS. The Univ. of California has given **Coors Porcelain Co.,** Golden, Colo., a contract to develop a ceramic in which radioactive wastes can be permanently entrapped; the program, in which Coors will work with Los Alamos Scientific Laboratory, is an extension of work Coors has been doing on ceramic sponge for some time. . . . AEC has given **Franklin Institute** a $72,000 research contract for an exhaustive study of machinery and materials both available and required for high-temperature gas-cooled reactors (up to 2,500 deg F). . . . **Cleveland Pneumatic Industries** will study conditions at two waste disposal sites off the California coast for AEC, at an estimated cost of $60,000. . . . **Martin Co.** is developing a series of computational codes for AEC, under a $335,000 contract (first-year cost of a 3-year program), and has been given a $2.3-million renewal of its contract with AEC on development of isotopic-power sources; the renewal expires June 30. . . . **Henry C. Beck Co.,** Atlanta, was winning bidder—$4,871,000—to build a Metals and Ceramics Facility at Oak Ridge National Laboratory (completion in late 1961). . . . **M & C Nuclear** was the winning bidder to fabricate 39,800 pieces of depleted uranium (60 tons) for Argonne National Laboratory. The contract, $218,330, covers about half Argonne's blanket requirement for its new Zero Power Reactor (ZPR-VI) for fast-reactor studies. Argonne subsequently doubled the order, M & C reported.

FINANCIAL. Record sales and earnings in '59 were reported for both **Metals & Controls** and its parent firm, **Texas Instruments.** . . . **Nuclear Materials and Equipment Corp.** has filed a registration statement with the Securities and Exchange Commission covering 45,000 shares of common stock; 40,020 shares would be sold to raise more than $1-million (NU, Jan. '60, 20). . . . **Victoreen Instrument** reported an upsurge in both sales and earnings in '59, reflecting both acquisitions and increased sales. Earnings were $390,950 (25 cents/share) on sales of $7,776,761; the comparable '58 figures were $242,547 (16 cents/share) and $5,449,340. . . . **Landsverk Electrometer** reports current business is "very good," with commercial orders picking up faster than government orders and representing more than half of total sales (against 40% in '59). . . . **Tracerlab** reported a loss of $482,537 on sales of $10,743,891. However, new orders were coming in at an annual $15-million rate.

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NEWSMAKERS

Charles E. Stevenson, former technical director of the Idaho Chemical Processing Plant, has joined the Idaho div. of Argonne National Laboratory to direct the chemical processing and fuel-refabrication phase of the fuel-cycle facility being built for EBR-2 (AEC's second Experimental Breeder Reactor).

President Eisenhower has appointed **Alvin M. Weinberg,** director of the Oak Ridge National Laboratory, to his 21-member Science Advisory Committee. Weinberg succeeds Cyril Smith of the Univ. of Chicago; his term will expire Dec. 31, 1962. The Committee advises the White House on major policy matters involving science, including such things as the country's posture in high-energy physics research.

Weinberg

A former project leader at Vitro Laboratories, **Charles J. Anderson,** has joined Cross-Malaker Laboratories as a research engineer specializing in nucleonics and radiochemistry.

J. Calvin Brantley has been named director of research, Union Carbide Nuclear Co. He will direct research work at the firm's new Sterling Forest Research Center, Tuxedo, N. Y., where lab and reactor facilities are being completed for nuclear and minerals work. Brantley had been assistant director of research since mid-1959.

Brantley

New officers of the Institute of Nuclear Materials Management: Chairman, **Ralph F. Lumb,** director, Western N. Y. Nuclear Research Center; vice-chairman, **Thomas B. Bowie,** Combustion Engineering; secretary, **William B. Thomas,** Westinghouse Bettis; and treasurer, **Sheldon Kops,** AEC Chicago Operations Office.

N. L. Rawlings has left his executive vice-presidency, Newport News Shipbuilding & Dry Dock Co., to devote full time to the firm's nuclear projects. His new title: vice-president, nuclear power activities.

Michigan Univ. has named **William Kerr** of the engineering faculty to associate director of the Michigan-Memorial Phoenix Project, under **Henry J. Gomberg.**

Allan Bromely, a senior scientist at the Atomic Energy Center of the National Research Council of Canada, Chalk River, has been appointed associate professor of physics at Yale Univ. He will do research work in Yale's electron and heavy-ion accelerator program.

Robert E. Macherey has been appointed associate director of the Metallurgy div. at Argonne. He succeeds **James F. Schumar,** who recently joined General Atomic div. of General Dynamics. Macherey will coordinate the work of all seven engineering groups in the division; he was formerly leader of one of these—the Foundry and Fabrication group. Division director is **Frank G. Foote.**

Macherey

Irvin N. Zimet has been elected vice-president and assistant-to-the-president, Victoreen Instrument.

Tracerlab's Chemistry dept. chief, **Marvin A. Stolberg,** has left the firm to join New England Nuclear Corp. as assistant technical director. He directed all activity on labeled compounds at Tracerlab.

Pacific Coast Engineering Co., a major supplier of reactor pressure vessels, has named **Gavin Embry** industrial engineering manager. A specialist in organization and systems planning, Embry joined Paceco from Kaiser Engineers, where he was manager of organization and procedures. He is a member of the Operations Research Society and the Society for the Advancement of Management.

At Knolls Atomic Power Laboratory, **Richard A. Young** has been named manager of manufacturing control (dealing with vendors, as well as traffic control for the Lab) and **Robert B.**

McCalley, Jr., has been named a consulting engineer to the Submarine Advanced Reactor project.

J. Richard D'Ardenne has been promoted from field engineer to area head of the Nuclear Systems group, Leeds & Northrup Co.

CompuDyne Corp. has appointed **Robert Newton Brey, Jr.,** market development manager. Brey was project manager at Leeds & Northrup, where he directed development of reactor-control instrumentation. CompuDyne manufactures closed-loop electrohydraulic control systems for nuclear and other industries.

Donald A. Berg has been named manager of nuclear projects at Interstate Electronics Corp.

Britain's General Electric Co. has appointed **R. N. Millar,** chief reactor designer and a director of the firm, to managing director of the company's engineering group—in charge of all nuclear, mechanical and heavy-electrical engineering.

Justin L. Bloom, former AEC employee, has been named a project engineer for advanced SNAP programs in the Nuclear div., Martin. The firm's SNAP work is the development of isotopic power sources for Secondary Nuclear Auxiliary Power (outer-space applications). Bloom had been chief of the Materials Management branch of the San Francisco Operations Office.

Stanton T. Friedman has joined the Systems Development div. of Aerojet-General Nucleonics from the shielding unit of the General Electric Aircraft Nuclear Propulsion dept.

Frank W. Davis has left the Reactor Development div. at AEC to join Southwest Research Institute as technical consultant. He was a metallurgical engineer at AEC.

Radiation Applications, Inc., has added **William Oliver** of American Cyanamid to its staff as a research chemist for radiation grafting development.

Howard A. Wilcox has been named director of research and engineering in the Defense Systems div., General

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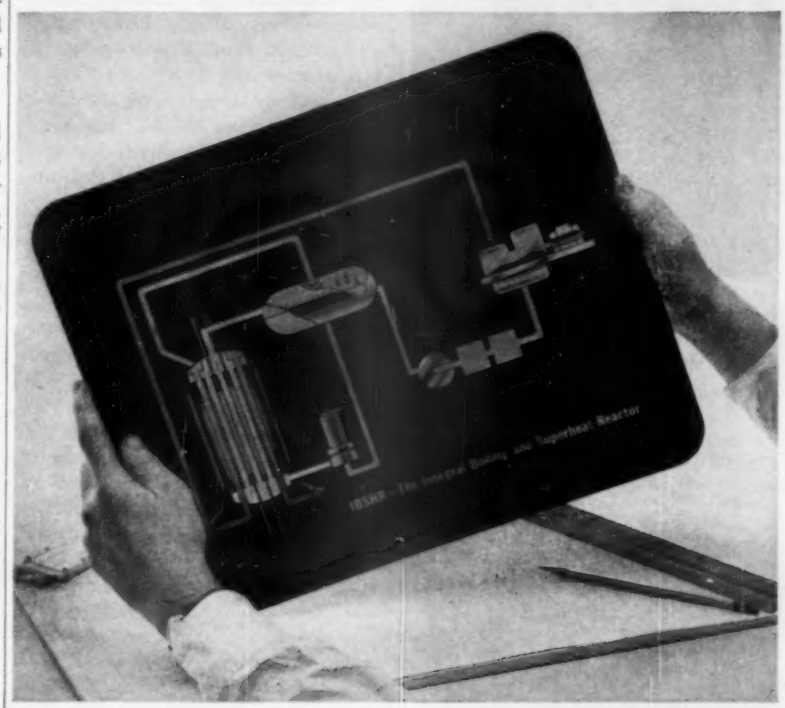

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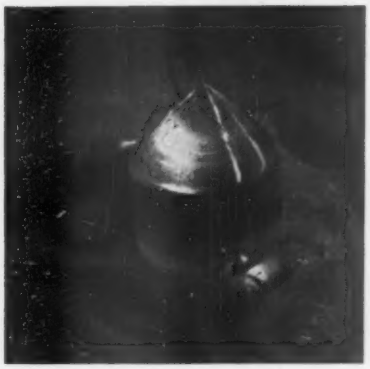

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NEWSMAKERS

Department starts on page 146

Motors. He has specialized in nuclear physics and guided missiles.

A new group in GE's Electric Utility Group—Electric Utility Marketing Operation—will be managed by **Milton F. Kent.**

Francis L. Jackson has been appointed technical director for mechanical and nuclear engineering, Franklin Institute Laboratories.

A former staff member of the Central European Laboratory of Nuclear Research, Italian theoretical physicist **Vladimir J. Glaser,** has been appointed a professor in the Physics dept., Maryland Univ.

Lewis M. Branscomb has been selected to direct a new division at the National Bureau of Standards—Atomic Physics. The division was broken off from the former Atomic and Radiation Physics div.; **Lauriston S. Taylor** remains as chief of this renamed division—Radiation Physics.

Frank M. Comer has left the Radioisotope dept. of the Menorah Medical Center, Kansas City, to join Nuclear Consultants Corp., where he will handle the firm's consulting work in Ohio, Michigan and western Pennsylvania.

Carlo Salvetti, the director of Italy's Ispra Research Center (in the process of being turned over to Euratom) has joined the International Atomic Energy Agency as director of the Research and Laboratories div.

G. C. J. Dalton has been appointed director of Australia's Lucas Heights Research Establishment; he was formerly chief engineer and deputy chief scientist in the Australian Atomic Energy Commission.

The Nuclear div. of American Electronics has brought in a second General Electric man to fill a top post. **Joseph W. Ranftl** left GE's X-ray dept. to take the marketing-manager post (NU, March '61, 162) and **Luther Welsh** has left GE's Vallecitos Atomic Laboratory to assume the position of chief engineer at American Nuclear. Welsh was assistant to the manager at Vallecitos, handling the internal development program and contract administration.

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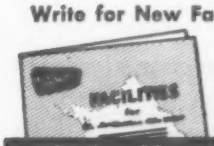

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NUCLEAR CAMPUS

● **Southern Illinois Univ. Foundation** has launched a campaign to raise at least $1-million for the installation and operation of a 5.5-Mev Van de Graaff accelerator. SIU estimates it needs $450,000 to erect an accelerator building, another $450,000 for the machine, and $100,000 per year to operate it for nuclear and other research.

● **Univ. of Texas** will install its second reactor next year, with the help of grant funds from AEC. The school has recently completed installation of a subcritical reactor purchased from Lockheed Aircraft Corp.

● One school has been cleared by AEC for operation of a training reactor and two others have been cleared for reactor construction. **North Carolina State College** was to go ahead with operation —after final AEC inspection—of a 10-kw reactor built by Nucledyne div. of Cook Electric Co. Of the two schools building reactors, the **Univ. of Illinois** expects to have its General Atomic Triga Mark II reactor completed by July at a total cost of $357,000 for reactor and associated lab; the **Univ. of Kansas** is purchasing a 10-kw pool-type reactor from Bendix Corp. for installation in a new building on the western edge of the main campus.

● **Florida State Univ.** has been given a $3-million AEC contract to conduct a broad research program in living organisms, including fundamental research on the growth of cancer cells. With award of the contract by AEC's Biology and Medicine div., FSU is establishing the Institute of Molecular Biophysics under Michael Kasha.

COURSES. Univ. of California Extension, Berkeley, is offering **criticality and criticality problems,** June 20–July 1; tuition fee is $250.

Marquette Univ. is offering a graduate program in **nuclear engineering,** beginning this September; the school, expanding its nuclear program at both graduate and undergraduate levels, also plans to introduce the **metallurgy of nuclear materials** and a series of short courses and institutes for local industry on the **industrial uses of radioisotopes.**

Cornell College, Mt. Vernon, Iowa, is offering **radioisotopes and their uses,** June 13–24, for college and junior college teachers of biology, chemistry and physics.

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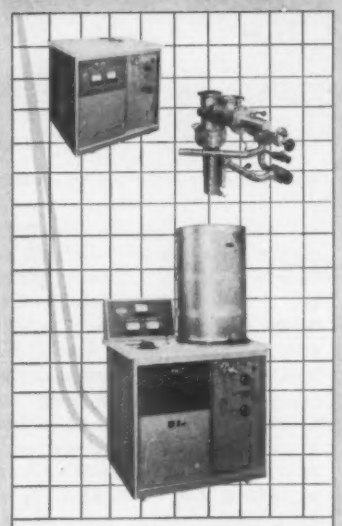

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May 4–6—Conference on Properties and Applications of Materials in Aerospace Vehicle Design, sponsored by Martin Co., Denver, Colo. Session on nuclear rocket motors. Contact K. R. Agricola, Mail No. L-8, Martin Co., Box 179, Denver 1.

May 9–11—3rd National Power Instrumentation Symposium, sponsored by Instrument Society of America, San Francisco. Contact ISA, 313 Sixth Ave., Pittsburgh 22, Pa.

May 9–13—Instrument Society of America, San Francisco. For papers on measurement and control instruments contact Martin E. Kantor, c/o General Atomic, P. O. Box 608, San Diego 12, Calif.

May 10–13—Symposium on Fuel Element Fabrication (emphasis on cladding materials), sponsored by International Atomic Energy Agency, Vienna.

May 12—Advanced Propulsion Reactor concepts, unclassified session at American Rocket Society semiannual meeting, at Los Angeles (*Ambassador*). Contact C. J. Wang, c/o Space Technology Labs, Box 95001, Los Angeles 45.

May 16–17—Radioisotope Workshop, Dallas, Tex., sponsored by AEC, Chance Vought Aircraft, Southern Methodist Univ. and a group of Texas organizations. Contact G. R. Armstrong, Aeronautics Div., Chance Vought, Dallas, Tex.

June 5–9—World Power Conference on Solving Power Shortage Problems (Sectional Meeting), sponsored by International Executive Council of World Power Conference, Madrid, Spain. Contact D. José Pérez Pozualo, Spanish Natl. Committee, General Pardinas, 55, Madrid.

June 7–11—IAEA Symposium on Radiation Dosimetry, Vienna. **Aug. 8–12**—IAEA Symposium on Ionizing Radiation Effects on Seeds and Improvement of Crops, Karlsruhe, Germany. **Sept. 6–17**—IAEA Conference on Radioisotopes in Physical Sciences and Industry, Copenhagen. **Sept. 20–Oct. 7**—IAEA Fourth General Conference, Vienna.

June 12–15—Annual Meeting of American Nuclear Society, Chicago (*Palmer House*). Contact Octave J. DuTemple, 86 E. Randolph St., Chic. 1.

June 15–29—International Congress and Exhibition on Electronics, Nuclear Energy and Cinematography, Rome (*Palazzo dei Congressi*). Contact Evandro Benvenuti, Via della Scrofa, 14, Rome.

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June 20–21—First Annual Meeting of Institute of Nuclear Materials Management, Columbus, Ohio (*Neil House*). AEC is holding its Annual Materials Management Meeting at same location June 23–25. Contact Harley L. Toy, Battelle Memorial Institute, Columbus.

June 20–26—Congress on Nuclear Energy, sponsored by Italy's Comitato Nazionale per le Ricerche Nucleari (CNRN), Rome. Contact C. M. C. Office, CNRN, Via Belisario 15, Rome.

June 23–24—2nd Youth Conference on the Atom, Univ. of Michigan, Ann Arbor. Contact Bozell & Jacobs, 2 W. 45th St., N. Y. 36, N. Y.

June 29–July 1—Annual meeting, Health Physics Society, Boston (*Statler-Hilton*). Contact E. B. Anderson, Oak Ridge Natl Lab, Oak Ridge, Tenn.

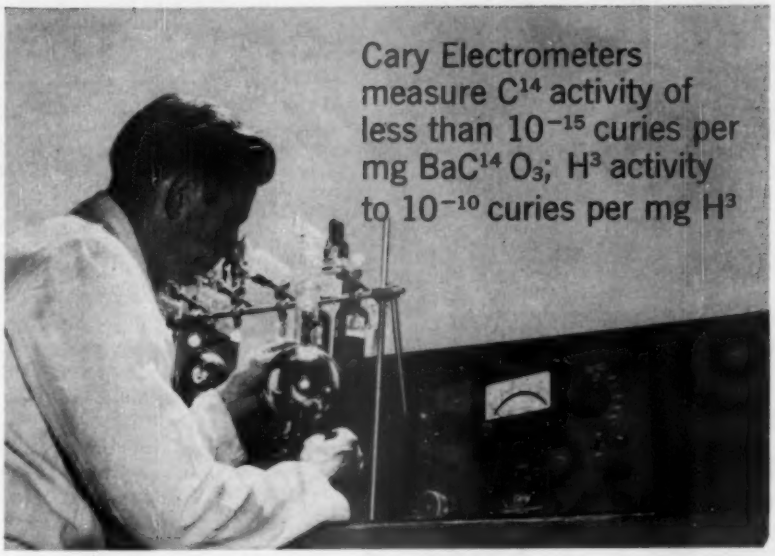
July 21–27—3rd International Conference on Medical Electronics, London. Contact Secretary, Institution of Electrical Engineers, Savoy Place, London W. C. 2, England, or Lee B. Lusted, Dept. of Radiology, Univ. of Rochester School of Medicine, Rochester 20, N. Y.

Aug. 11—AEC information meeting on small reactors, Oak Ridge. Contact R. A. Charpie, ORNL, Box 4, Oak Ridge.

Aug. 29–31—U. S. Public Health Service Symposium on Water Quality Measurement and Instrumentation, Cincinnati, Ohio (*Sanitary Engineering Center*). Emphasis on automatic instrumentation. Contact Director, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Pkwy., Cincinnati 26.

Sept. 13–15—Fifth International Instruments and Measurements Conference, including section on nuclear instrumentation, and an exhibition of commercial instrumentation, Stockholm. Contact H. von Koch, Royal Institute of Technology, Stockholm 70, Sweden.

Dec. 11–16—American Nuclear Society-Atomic Industrial Forum joint meeting, San Francisco (*Mark Hopkins* and *Fairmont*). 12–15th Atomfair West, first West Coast nuclear industrial exposition (*Masonic Memorial Building*). Contact W. Kelly Woods, Vallecitos Atomic Laboratory, Pleasanton, Calif., for ANS program; Edwin Wiggin, AIF, 3 E. 54 St., N. Y. 22, for Forum program; Dan Scherer, AIF, for Atomfair. 11–14—8th Hot Laboratory and Equipment Conference. Paper summaries due May 16. Contact James R. Lilienthal, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, N. M.



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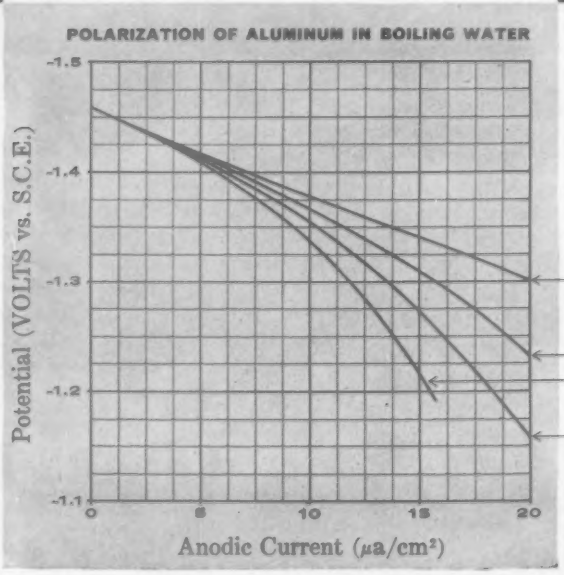

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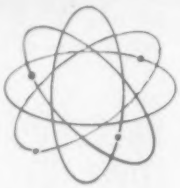

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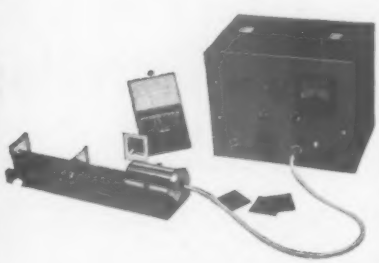

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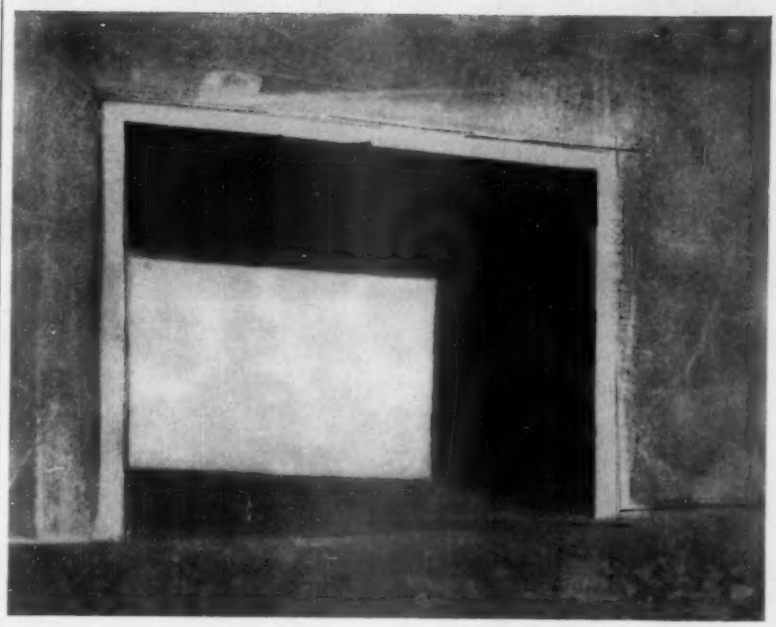

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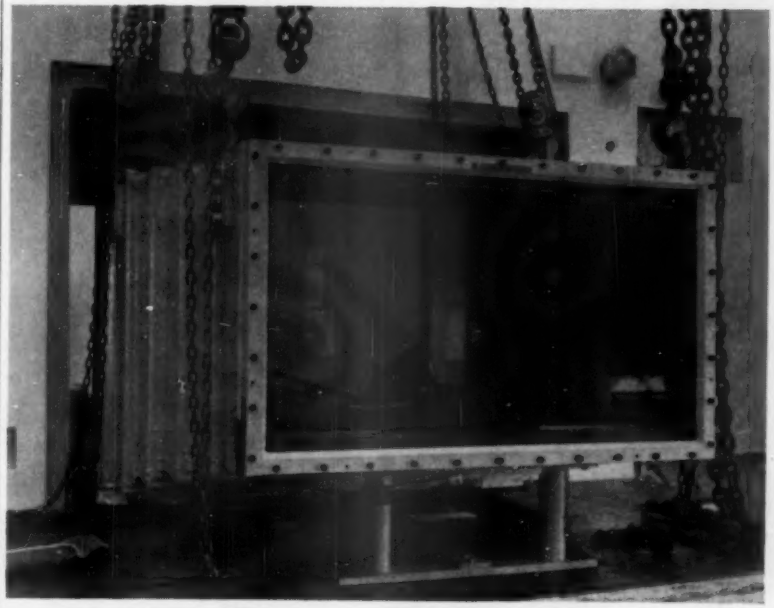

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Model	Dimensions with cap and #82 connector	Active length	Operating voltage at standard pressures of gas in centimeters of mercury					Price (aluminum cathode)	Price (brass) or copper
			20cm	30cm	40cm	48cm	60cm		
Micro-neutron	¼"x 3"†	¼"–1"	1100	1250	1400	1500	1700	$ 75.	$ 75.
G-5-3	⅝"x 6½"	2½"	1400	1700	1900	2100		95.	75.
G-5-9	⅝"x12½"	8½"	1400	1760	1900	2100		100.	80.
G-5-16	⅝"x20"	16"	1400	1700	1900	2100		110.	90.
G-10-5	1" x 9"	4½"	1500	1800	2000	2200	2050*	115.	100.
G-10-12	1" x17"	12"	1500	1800	2000	2200	2050*	125.	110.
G-10-20	1" x25"	20"	1500	1800	2000	2200	2050*	135.	120.
G-15-12	1½"x17"	12"	1700	1950	2150	2350		140.	125.
G-15-34	1½"x39"	34"	1700	1950	2150	2350		190.	175.
G-15-34A*	1½"x41½"	34"	1700	1950	2150	2000*		190.	175.
G-20-12	2" x17"	12"	1900	2100	2300			160.	140.
G-20-20	2" x25"	20"	1900	2100	2300			180.	160.
G-20-38	2" x43"	38"	1900	2100	2300			225.	200.
G-20-46	2" x51"	46"	1900	2100	2300			275.	250.
Shielded cable with #82-804 teflon connector									10.

Model F: Depleted BF_3, 11% boron 10—prices and dimensions same as above.
* Made with smaller anode. † Without cap and connector.

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Model	Dimensions with open-end cap	Active length	Operating voltage	Plateau, length	Slope per 100 volts	Length of life, counts	Price
D-5-3	⅝"x 6½"	2½"	1000	200 v.	2%	10^8	$15.
D-5-9	⅝"x12½"	8½"	1000	200 v.	2%	10^8	15.
D-5-16	⅝"x20"	16"	1000	200 v.	2%	10^8	15.
D-10-5	1" x 9"	4½"	1050	200 v.	2%	10^8	20.
D-10-12	1" x17"	12"	1050	200 v.	2%	10^8	25.
D-10-20	1" x25"	20"	1050	200 v.	2%	10^8	25.
D-15-5	1½"x 9"	4½"	1100	300 v.	1%	10^9	25.
D-15-12	1½"x17"	12"	1100	300 v.	1%	10^9	25.
D-15-20	1½"x25"	20"	1100	300 v.	1%	10^9	30.
D-15-34	1½"x39"	34"	1100	300 v.	1%	10^9	30.
D-20-12	2" x17"	12"	1200	300 v.	1%	10^9	30.
D-20-20	2" x25"	20"	1200	300 v.	1%	10^9	35.
D-20-30	2" x35"	30"	1200	300 v.	1%	10^9	40.
D-20-38	2" x43"	38"	1200	300 v.	1%	10^9	45.
D-20-46	2" x51"	46"	1200	300 v.	1%	10^9	50.
Cap with #83 connector							5.

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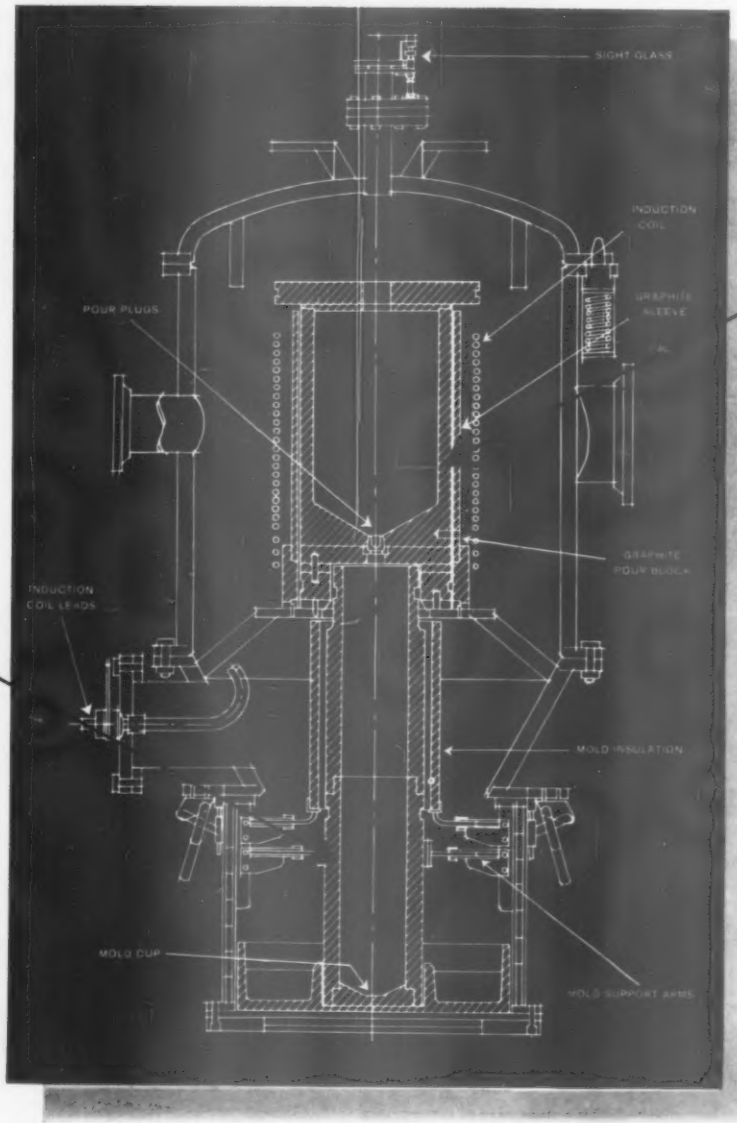

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